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MANUFACTURING METHODS FOR PROCESS EFFECTS ON ALUMINUM CASTING ALLOWABLES

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MARCH 1985

FINAL REPORT FOR PERIOD 10 APRIL 1980 TO 10 JULY 1984

MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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FOR THE COMMANDER:

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This program was accomplished in two phases, I and II. Both phases were conducted in two parts, A and B.

Phase IA established the status of premium quality aluminum foundry technology and identified the need for user-design documentation. Phase IB demonstrated the foundry processing effects that are major contributors to casting properties of aluminum castings.

Phase IIA established foundry process control and inspection procedures needed to optimize casting properties. Phase IIB incorporated these procedures into a comprehensive test program. The object of this test program was to establish reliable design information and documentation for the design and procurement of premium quality alumimum castings.

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FOREWORD

This final technical report covers the work performed under Contract F33615-79-C-5116 from April 1980 to July 1984 by Northrop Corporation, Aircraft Division, Hawthorne, California under Project No. 268-9, Manufacturing Methods for Process Effects on Aluminum Casting Allowables. The program was administered under the technical direction of Mr. Kenneth L. Kojola, Metals Branch, Manufacturing Technology Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433.

Northrop's Metallic Materials Research and Advanced Manufacturing Technology Department, performed the work. Mr. Kermit J. Oswalt was the Program Manager, Dr. Yuli Lii and Mr. Charles Ford were the Principal Investigators.

The program manager wishes to acknowledge Messrs Jud Iler and Larry Zellman, for their many contributions; Mr. Paul Ruff, Battelle Columbus Labs, for the data analysis and for his leadership in the ad hoc casting group of the MIL-HDBK-5 committee which assisted in the development of the proposed specifications; Mr. K.C. Wu on the development of the A201 welding process; and Mr. S.M. Hsu, for the mechanical testing performed during the program.

The major subcontractors on the program were The Arwood Corporation, Tilton, New Hampshire; Cercast, Inc., Montreal, Canada; Hitchcock Industries, Inc., Minneapolis, Minnesota; Teledyne Cast Products, Pomona, California; Magnesium Alloy Products, Gardena, California; Morris Bean and Company, Yellow Springs, Ohio; and Smithford products, Ontario, California.

This report covers work conducted from April 1980 to July 1984.

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SUMMARY

1. SUMMARY

a. Foundry Manufacturing Technology and User Documentation

A comprehensive survey of airframe manufacturers and their premium quality casting suppliers was made to establish the status of foundry manufacturing technology and the need for design documentation. It was determined that:

1. Foundry manufacturing capability varies considerably within the industry because of the technology, equipment and interest of the foundry.

2. The manufacturing process variables which are involved in the manufacture of premium quality aluminum castings have been identified; however, the significance of each variable on casting properties must be determined to advance the state of the foundries manufacturing technology and assure the integrity for structural aircraft components.

3. Inspection techniques and criteria are needed to identify the significant characteristics of a material of acceptable properties.

4. The following information is needed to expand the use of premium quality aluminum castings into structural airframe components:

   (a) MIL-HDBK-5 design properties supported by proven quality assurance provisions of the material specification

   (b) Clarification of the casting factor requirements of military and company documents to permit castings to be designed in a manner similar to wrought materials

   (c) Data for damage tolerance designs.

b. Effect of Manufacturing Process Variables

The effect of the manufacturing process variables of shell investment and sand composite production methods on the tensile properties of alloys A356, A357, and A201 was demonstrated.

It was shown that the major variables of the manufacturing process which must be controlled to optimize the tensile properties of castings of all three alloys produced by both molding processes were alloy and impurity content of the melt composition, radiographic quality and coarseness of casting microstructure, and variations of the heat treat process. Each variable is capable of independently causing significant degradation to prevent optimization of casting tensile properties unless controlled to within tighter limits of acceptability than currently specified in procurement specifications.

c. Procurement Specification

Material specifications were developed for the procurement of A201-T7 and A357-T6 structural aircraft castings. The acceptance criteria were based on a comprehensive evaluation of the effect of manufacturing process variables on tensile properties of castings. Quality acceptance procedures were generated which verify the effectiveness of the foundry process controls. These procedures were incorporated in the specifications as acceptance inspection test procedures.

d. Quality Assurance Acceptance Testing Methods

Acceptance testing procedures were developed to ensure consistency and reliability of the material accepted for flight critical structures. These procedures vary from those currently used in military or other material specifications. The effects of variations in the manufacturing process were found to be related to the radiographic quality, heat treat response, and microstructure of the casting.

e. Design Property Data

Castings, produced by two foundries, employing a minimum of 10 melts and 4 heat treat lots, were poured in each alloy and evaluated to develop statistical design properties in accordance with the guidelines of MIL-HDBK-5. Design property values of the A357-T6 cast material were established on a statistical A and B property basis. The A property values were 50.6 ksi UTS and 42.1 ksi YS. The B values were 52.2 ksi UTS and 43.7 ksi YS. The casting properties of A201-T7 cast material varied in a non-normal manner above the minimum requirements and, therefore, only specification(s) values could be determined. These were 60 ksi UTS and 50 ksi YS. Strength ratios for design properties of compression, shear, and bearing were also determined for each alloy. This information was used to prepare a design property table for each alloy.

f. Fatigue Properties

The notched fatigue endurance limit of A357-T6 and A201-T7 was shown to be approximately 13 ksi and 9 ksi respectively; however, additional testing is needed to establish the endurance limits with confidence.

g. Fracture Toughness

The fracture toughness results were invalid for K_{IC} values; however, K_Q values varied from 25.4 to 26.7 ksi in.1/2 for A357-T6 material and 23.3 to 33.2 ksi in.1/2 for A201-T7 material.

h. Fatigue Crack Growth Properties

The crack growth behavior of A357-T6 material was similar to alloy 7075-T7351 and the A201-T7 material was judged similar to alloy 2124-T851.

i. Weld Improvement Properties

Cast A357-T6 and A201-T7 material which had been welded to a depth of 50 percent of the wall thickness were reheat treated and tested for notched

fatigue, fracture toughness, and tensile properties. In comparison with the properties of parent material, the tensile properties of the welded material of both A357-T6 and A201-T7 were very similar, the notched fatigue and fracture toughness of the welded A201-T7 were better than the parent material; the fatigue properties from welded A357-T6 material showed a slight degradation in comparison with those of parent material after 500,000 cycles, and the fracture toughness properties of welded A357-T6 were similar to the toughness of the parent material.

j. Effect of Radiographic Flaws

Cast material of A357-T6 and A201-T7 containing C-D grade radiographic quality per MIL-C-6021 were evaluated. Tensile and notched fatigue properties of A357-T6 material were reduced due to shrinkage and porosity however, sponge shrinkage at a similar quality level did not affect the fracture toughness. Grade D gas porosity reduced the tensile and notched fatigue properties and to a lesser degree also reduced fracture toughness of A201-T7 material.

k. Cost Analysis

Castings of various complexity and configurations were analyzed for the most economical method of production. Cast shapes were found to be most economical in more complex configurations while other production methods were cost-effective for simple configurations.

SECTION I
INTRODUCTION

1. BACKGROUND

Although the manufacturing technology for producing premium quality castings has been known for more than 20 years, general acceptance and use of this cost-saving technology by the aerospace industry has been extremely limited. There are two reasons for this reluctance: (1) the use of casting design factors results in excessive and costly weight penalties and (2) aerospace users have had a low level of confidence in the foundry's ability to consistently manufacture acceptable castings. This program is based on the premise that castings produced to predetermined quality criteria exhibit a predictable tensile property capability. The properties of the casting are controlled by the foundry manufacturing process which determines the metallurgical quality of the material. Once the effect of the manufacturing process variables are known and related to the metallurgical quality of the material, the casting properties will not change unless there is a change in the quality of the material.

The lack of adequate controls by both foundry and user has been an inherent problem in the production and use of premium quality castings. This has resulted in numerous situations where the user and the producer do not agree on the metallurgical acceptance criteria. This situation has evolved from both an inadequate understanding of the manufacturing parameters and process control variables affecting mechanical properties, and a lack of an accepted industry approach. Needed are specific control and acceptance procedures to ensure consistent quality castings with reliable mechanical properties.

The purpose of this program was to identify processing variables that affect casting properties, to establish design property values, and to demonstrate nondestructive inspection techniques that could reliably predict and correlate with the casting component properties. This information is needed to extend the use of cast structures in airframe designs and to reduce Cont'd

the manufacturing cost of aircraft. The cost-reduction benefit generally increases proportionally with the part size and complexity.

2. OBJECTIVE

The general objective of this program was to establish the relationship between allowable design properties and manufacturing processes used to produce premium quality aluminum castings for primary aircraft structure. Specific program objectives were:

1. Establish realistic minimum design properties at a confidence level level that would encourage the use of aluminum castings for flight-critical structure

2. Demonstrate process controls and quality assurance techniques that would eliminate the need for casting factors

3. Define methodology from design concept through casting acceptance

4. Develop MIL-HDBK-5 casting design-allowable data

5. Demonstrate cost-effectiveness of aluminum castings for aircraft structures.

3. PROGRAM APPROACH

The program was accomplished in two phases. In Phase I, a survey of airframe and casting manufacturers was made to understand the industry needs necessary to expand the use of cast structures. An evaluation of foundry processing was performed to identify those variables that must be controlled to optimize casting properties. In Phase II, NDI and process control procedures were correlated with the significant process variables to define a structural quality airframe casting procurement specification. Test castings procured to this specification were used to develop reliable design data for the manufacture of aircraft structures at lower cost.

4. MAJOR PROGRAM ACCOMPLISHMENTS

The major program accomplishments were as follows:

1. Demonstrated the effect of processing variables for shell investment and sand composite production methods on the mechanical properties of A356-T6, A357-T6 and A201-T7 cast materials.

2. Generated two material specifications for aircraft structural casting procurement with defined quality controls and optimum mechanical properties and one process specification for measuring DAS.

3. Developed design allowable data for MIL-HDBK-5.

4. Determined fracture toughness, fatigue and crack-growth information, and demonstrated the effect of repair welding and radiographic unsoundness on toughness and fatigue properties.

5. Developed NDI procedures and acceptance criteria to assure property reliability and consistency.

6. Demonstrated cost-effectiveness of cast structures.

SECTION II

CURRENT TECHNOLOGY AND UTILIZATION BASE

1. INTRODUCTION

A comprehensive survey was made of airframe manufacturers and their premium quality aluminum casting suppliers. A total of 18 foundries producing castings to the requirements of military specification MIL-A-21180, "Aluminum-Alloy Castings, High Strength" for the aerospace industry were surveyed. A listing of the foundries is shown in the Appendix A. Seven of the foundries used the shell investment process and eleven foundries produced aerospace castings by the sand composite molding process. Thirteen airframe manufacturers were surveyed. These were Boeing (Wichita and Seattle), Fairchild, General Dynamics, Grumman Aerospace, Lockheed (California and Georgia), LTV, McDonnell-Douglas (Long Beach and St. Louis), Northrop, Bell Helicopter, and Hughes Helicopter.

The responses obtained from these surveys are summarized in Appendices A and B.

2. FOUNDRY PRODUCTION METHODS

The airframe industry primarily uses aluminum castings which are produced by the shell investment or the sand composite molding processes. The survey was therefore limited to foundries employing these processes for the production of airframe MIL-A-21180 type castings.

The shell investment and sand composite molding techniques are well known and described in published literature. These molding techniques can be used to produce castings of various strength levels, except that each technique has an upper limit that is practical to obtain in a specific casting configuration. The dimensional quality in general is better in castings produced in investment molds than in sand composite molds. However, the strength of sand composite molded castings is generally superior to those produced in shell investment molds.

Complex, high quality castings are always more difficult to produce to minimum tolerance requirements than simpler configurations of lower quality.

a. Critical Metallurgical Variables

The critical metallurgical variables which must be controlled in order to produce premium quality castings have been documented in numerous papers. Many of these are included in the bibliography of this report. The success of obtaining premium quality is determined by the capability of the foundry to control processing. The critical metallurgical variables which are controlled by foundry processing are:

1. Chemistry
2. Solidification rate
3. Soundness
4. Heat treatment

The importance of specific processing factors changes with the alloy, and with the strength and quality level desired. In this portion of the program, the process control employed by the foundry to optimize the strength properties of each alloy and process was reviewed.

b. Process Control Equipment Type and Tests

The type of testing used by the foundries surveyed to maintain process control was as follows:

TEST	PROCESS	
	Sand Composite	Investment
Melting		
Spectographic	x	x
Vacuum test	x	x
Temperature	x	x
Pouring temperature		
Pyrometer	x	x

TEST	PROCESS Sand Composite	Investment
Soundness		
As-cast x-ray	x	x
As-cast penetrant	x	x
Heat Treatment		
Hardness	x	x
Conductivity*		x
Sep. cast T/B**	x	x
Attached T/B	x	***
Gated T/B		x
Excised T/B	x	***

NOTES: * For A201 only
** T/B - test bar
*** May be prolongation

The purpose and type of equipment used for each molding process was as follows:

Equipment	Purpose	Used By Sand Composite	Investment
Spectrograph	Melt chemistry	x	x
Gas detector	Melt gas content	x	x
Pyrometer	Melt temperature	x	x
X-ray	As-cast quality	x	x
Penetrant	As-cast quality	x	x
Tensile	H.T.* control	x	x
Hardness	H.T. control	x	x
Metallograph	Resolve problems (grain size. DAS, etc.)	x	x
Camera	Document molding	x	x

NOTE: *H.T. = Heat treat

c. Process Documentation

Manufacturing variables which were documented for control were as follows:

	Investment P/N	Investment G	Sand Composite P/N	Sand Composite G
Melting		x		x
Chemistry	x	x	x	x
Mold assembly	x		x	
Rigging	x		x	
Chilling	x		x	
Pouring temperature	x		x	
Solution treatment (T&T)	x	x	x	x
Quenchant (type & temp.)	x	x	x	x
Aging treatment (T&T)	x	x	x	x
Weld repair	x	x	x	x

NOTES: P/N - document for each part number
G - general document
(T&T) - time and temperature

d. Strength Property Capability

Each foundry was asked to define the strength property capability of their process. The results were as follows:

	Sand Composite Ultimate/Yield/Elongation	Shell Investment Ultimate/Yield/Elongation
Alloy A356-T6		
Critical area:	45/34/3 - 38/28/5	43/32/4 - 38/28/3
Other area:	38/28/3 - 32/22/2	38/28/3 - 32/22/2
Entire casting:	None recommended	38/28/5 - 35/25/4
Alloy A357-T6		
Critical area:	50/40/5 - 45/35/3	50/40/5 - 33/27/3
Other area:	45/40/3 - 38/28/3	47/40/3 - 33/27/3
Entire casting:	None recommended	41/31/3 - 38/28/5

	Sand Composite Ultimate/Yield/Elongation	Shell Investment Ultimate/Yield/Elongation
Alloy A201-T7		
Critical Area:	60/50/3	60/50/5 - 55/45/3
Other area:	56/48/1 - 56/46/2	53/43/3 - 50/40/2
Entire casting:	60/50/3	60/50/3

Little agreement exists within the industry. Most of the investment foundry data were from prolongations or separately cast test bars in lieu of tensile specimens excised from castings. This is not an uncommon test procedure for investment castings due to their small size or thin wall configurations.

3. FOUNDRY AND USER RESPONSIBILITIES

To clarify the responsibilities of user and foundry, the survey asked both groups to identify areas which had caused confusion in casting procurement and to identify the areas of responsibilities. The response was as follows.

a. Problem Areas

The following items were identified as problems by either the foundry or the user:

1. Transferred tooling equipment usually needs modification
2. Foundry needs more time for quality development of first article
3. Drawing callouts are not always clear
4. Too many company specifications cause confusion at the foundry
5. Liaison personnel are not always knowledgeable in foundry procedures
6. Foundry does not identify problem areas during bidding process
7. Foundry does not test first article - lets user determine acceptability
8. Machined part drawing not supplied foundry

b. Foundry Responsibilities

The users generally require the foundries to be responsible for the following:

1. Storing and maintaining patterns and inspection equipment
2. Applying production control procedures that can effectively maintain shipping schedules
3. Developing shop aids necessary to control casting to drawing dimensions
4. Establishing process controls to maintain the required casting quality and workmanship

c. User Responsibilities

The foundries generally expect the user to be responsible for supplying the following:

1. Accurate drawings of the casting and machined parts
2. List of approved process facilities
3. Up-to-date company specifications as applicable
4. Shipping schedule requirements
5. Description of tooling to be used if available, at the time of request to quote

4. DESIGN PRODUCIBILITY CONCEPT OF USER

Airframe design groups did not maintain design producibility information which was related to premium quality castings. The concept was to apply the same design parameters for all qualities of casting and let the material specification handle to the quality requirements.

5. FOUNDRY SURVEY AND APPROVAL BY USER

Foundry surveys were generally conducted by the user's quality control department, which surveyed all foundry regardless of quality capability to the same requirements.

Qualified source lists maintained at the various user facilities do not identify those foundries capable of producing MIL-A-21180 type castings.

6. QUALITY ASSURANCE REQUIREMENTS OF USER

a. First Article Approval

Most users accepted the foundries' test results when available; however, the user still required preproduction castings. About one-half of the users excised tensile specimens from the sample casting and determined its capability to meet minimum requirements.

b. Production Testing

Production testing was done by the foundry at the user's approved testing source except for hardness testing and some excising of tensile specimens done by the user. Tests required were chemical analysis, penetrant, x-ray, hardness, and tensile properties of separately cast test bars or integral attached test bars and excised specimens from castings (destructive testing). Castings were selected at random, or as the least acceptable, for destructive testing. The frequency of testing was based on a "count," e.g., 1 in 20. Most users specified where the specimens were to be excised from the casting. Retesting was permitted if failure occurred through a radiographically acceptable flaw. Testing procedures were in accordance with ASTM Standard E8, "Tension Testing of Metallic Materials."

c. Process Welding

This was restricted in most instances to specific locations and sizes of areas to be repaired.

d. Traceability

Castings required vibro-etched or ink stamp markings for traceability of x-ray number in most instances and heat treat lot or melt number in a few instances.

e. Performance Records

All users maintain performance records of each foundry.

7. USER DOCUMENTATION DEFICIENCIES

a. Procurement Specification

All airframe manufacturers use MIL-A-21180 or a company specification written with similar requirements for procurement of premium quality castings. The following changes were recommended by the airframe manufacturers to make MIL-A-21180 more applicable to their individual company needs:

Recommended Changes	Number of Companies With Similar Comment
Add provision for a qualified source list	2
Remove MIL-STD-105, "Sampling Procedures and Tables for Inspection by Attributes"	8
Eliminate requirement for higher x-ray grade of preproduction part	10
Add provision for allowing process welding	5
Add requirement for cast-on serial number	2
Change "required" H.T. procedure to "recommended"	2
Increase tensile property requirements for preproduction casting	1
Equate testing requirements with margin of safety	1
Remove "Options"	2
Add requirement for integral attached coupon or prolongation	6
Relate minimum properties to process	3
Define conditions which allow retesting	3

Recommended Changes	Number of Companies With Similar Comment
Provide for testing of casting too small to excise tensile specimen	2
Establish QA test requirement for each process variable	2
Eliminate 5-percent elongation requirement	1
Remove requirement to negotiate properties with foundry	1
Relate to margin of safety	1
Reduce testing frequency as confidence increases	1
Remove alloy and property requirements (use drawing notes)	1
Improve tensile test procedure (defects have greater effect on smaller specimens; therefore, property minimum should be lower)	1
Relate x-ray quality and tensile properties	1
Define surface quality	1
Delete alloys C355, 354, and A357	1
Delete grade "A" x-ray requirement	1

b. User Property Requirements

The user tensile property requirements varied as follows for each process and alloy:

	Sand Composite Ultimate/Yield/Elongation	Shell Investment Ultimate/Yield/Elongation
Alloy A356-T6		
Critical areas:	40/30/3 - 38/28/4	Not specified
Noncritical areas:	38/28/3 - 30/20/3	Not specified
All areas:	38/28/5 - 38/28/4	40/30/3 - 30/20/3 and 38/28/3-5

	Sand Composite Ultimate/Yield/Elongation	Shell Investment Ultimate/Yield/Elongation
Alloy A357-T6		
Critical areas:	50/40/3-5 - 48/40/5	41/31/3
Noncritical areas:	44/34/4 - 38/28/3	38/28/3
All areas:	48/36/5 - 38/28/3	41/31/3 - 38/28/3-5
Alloy 201-T7		
Critical areas:	60/53/3	Not specified
Noncritical areas:	56/53/2	Not specified
All areas:	60/50/3 - 53/48/3	60/50/3 - 55/46/2

Note that the investment casting properties required for alloy A356 were very similar to those generally required for sand composite casting of alloy A356.

Investment casting property requirements of most users were applied at the same strength level for the entire casting. The property requirements that were applied to sand composite castings usually varied for critical and noncritical casting areas, although some users applied only one property strength level to the entire casting. The difference in approach, as related to the foundry process, is understandable since investment castings generally are much smaller and therefore, not subjected to a detailed stress analysis within the various areas of the casting.

c. Structural Analysis Requirements

This is a critical area of each user's design process that defines differences between premium and normal aircraft quality castings. The group classifies each casting in accordance with MIL-C-6021 "Castings, Classification and Inspection of." Class 1 castings are subjected to static testing to prove the design is acceptable prior to production use. This is a one-time test only. A casting factor is used in most airframe designed castings because of the requirements of MIL-A-008860, "Airplane Strength and Rigidity Ground Test," which states: "Calculated margins of safety using 'A' values

from MIL-HDBK-5 shall be not less than 0.33 for limit and ultimate calculations." The design factor applied by various design groups was found to vary up to 3.00 in some instances.

d. Information Needed to Use Castings for Primary Structure

This includes (1) design test data and quality assurance requirements which will eliminate the need for a casting factor, (2) damage tolerance, fatigue and fracture toughness information, and (3) realistic design allowables in MIL-HDBK-5.

SECTION III

UPDATE OF CURRENT TECHNOLOGY STATUS AND A REVISED SYSTEMS APPROACH

1. INTRODUCTION

The objective of this task was (1) to up-date the current technology status with a revised systems approach to casting design, procurement, and acceptance, (2) to identify technical areas that need further improvement or pertinent factors which need clarification, and (3) to propose specifications which would include foundry control procedures to be defined later in the program.

2. PROPOSED APPROACH FOR CASTING DESIGN, PROCUREMENT, AND ACCEPTANCE METHODOLOGY

a. Design Concept

The first step in a component design is the preparation of a drawing of the finished part. This is done to define the tolerances and quality required for the part to function. If a casting is selected, the next step would be to prepare a drawing of the rough casting. The designer then designs the rough casting. The final design is discussed with design-to-cost personnel to arrive at an agreement about the most economical method of production. For simple configurations, the method of production can be ascertained from the design manual. As the shape becomes larger and more complex, the most economical method of production is more difficult to determine and separate study effort may be required by the design-to-cost group. In these instances, sketches or preliminary drawings are developed by the designer to obtain approximate cost estimates of various production methods. These methods may include machining a part from a forging or a plate as well as various casting methods.

Drawings are reviewed by producers of the various candidate parts to indicate dimensional and quality limitations. The estimate of part cost and the marked up drawing are returned to the design-to-cost group. Finishing costs are then determined and added to the cost of the rough part to arrive at the most economical method for producing the part.

b. Preliminary Drawing Preparation and Team Review

Using design guidelines for the selected molding process the preliminary casting drawing is developed for team review.

A team review of the preliminary casting configuration is used effectively to expedite release of drawings. The typical review team is comprised of a representative from each of the following departments:

1. Manufacturing Engineering
2. Quality Assurance
3. Procurement
4. Materials and Process
5. Engineering Liaison
6. Design-to-Cost
7. Design Engineering
8. Structural Analysis

The responsibility of each team member is as follows:

1. Manufacturing Engineering: Responsible for the dimensioning method to be used for machining purposes, e.g., need for check fixture, tooling points, datum planes

2. Quality Assurance: Responsible for the method used for casting acceptance before machining, i.e., the need for inspection fixtures and method of dimensional layout and control and coordination with manufacturing engineering

3. Procurement: Responsible for anything unusual which may create a procurement problem. Procurement may request supplier input regarding producibility, cost, and lead time; it can be very misleading, however, to discuss a pending design with only the representatives from one foundry. For large or complex castings, input from several foundries is desired to ensure that cost and schedules can support production requirements. Design changes can be considered at this time which improve casting producibility; results of these discussions are then considered by the review team to arrive at the final design

4. Material and Process: Responsible for the specifications and quality requirements for compatibility with the molding process and property requirements

5. Engineering Liaison: Responsible for any drawing features which have previously required Materials Review Board action and need to be avoided

6. Design-to-Cost: Responsible for trade-off decisions regarding producibility as related to cost

7. Design Engineering: Responsible for the feasibility of suggested drawing modifications

8. Structural Analysis: Responsible for use of the proper material and casting classification; also defines the areas of highest stress.

A check print of the rough casting and finished part drawing (a two-part drawing) is distributed to each team member by the team chairman. The chairman convenes the review team and all comments are finalized on one drawing which is given to the designer for incorporation.

c. Drawing Release

After the designer has incorporated all comments from the review team, the drawing vellum and the check print from the review team are forwarded to the design check group. The check group determines if the proper drawing format was followed and if the vellum reflects the changes shown on the check print from the team review. If correct, the vellum is signed off by the checker and inserted in the company drawing release system. The procurement group receives advance copies of the drawing to expedite procurement of the casting.

d. Casting Procurement

Procurement reviews the source list of foundries approved for the type of casting or molding method, alloy, and property level. If necessary, new suppliers are identified and surveyed at the request of the Procurement Group. The survey consists of a review of the potential foundry facilities by a representative from each of the following groups:

1. Procurement
2. Quality Control or Quality Assurance
3. Materials and Process Engineering

Each representative may survey the facility separately or together as a team. The airframe group representative's responsibilities are as follows:

1. Procurement: Responsible for evaluating the financial and company organizational stability of the foundry; also considers production control procedures and the ability of the foundry to respond to user requirements and corrective action requests

2. Quality Control: Responsible for evaluating the foundry process control, traceability procedures, and inspection equipment calibration and maintenance; also considers the position of the quality control manager in the company organization structure

3. Materials and Process Engineering: Responsible for evaluating the foundry level of technology and capability; also considers the documentation of procedures and controls applied to maintain a high level of quality.

The survey is coordinated by the casting buyer who advises the foundry of the results. Approved foundries are placed on an approved source list for the alloy, process, and property level approved.

e. Request for Quotation

After determining the approved sources, the foundries are requested to quote on production quantities. The quote package should contain and define the following:

1. New or existing tooling to be used; if new tooling is to be built, the life expectancy is stated, and availability of information needed to construct the pattern equipment

2. Three drawings of the casting, including the final machined part

3. Quantity and schedule requirements

4. List of approved processing sources

5. Testing responsibilities of the foundry.

In responding to the request, the foundry defines:

1. Costs and capability to meet proposed schedules

2. Deviations required or items requiring clarification.

f. Placement of Purchase Order

After review of all quotations, the casting buyer selects the casting

source and releases the purchase order in accordance with standard procedures of the Materiel Group.

g. Production Approval (First Article)

Requirements for production approval must be defined in the procurement material specification. The requirements define the following:

1. Minimum quantity of castings to be submitted

2. Test data, certifications, processing information, and any order of precedence that may be required; for instance, the x-ray technique should be approved by the user before the sample castings are submitted for production approval.

After the casting and information have been received, the user evaluates the castings and determines the acceptability limits to be used for subsequent production castings. These limits define the acceptance criteria for such items as follows:

1. Specific test sites of the casting for evaluation of tensile properties, and/or solidification rate tests

2. Yield strength range of acceptability of integral attached tensile coupon

3. Special quality requirements if any, for specific areas of the casting.

Processing control documentation is reviewed and, if approved, so indicated. The procedures are not approved for technical content, only to ensure that all pertinent variables are controlled.

The results of the user ·aluation are forwarded to the foundry and the user's receiving and inspection quality control group.

3. TECHNICAL AREAS NEEDING REFINEMENT OR CLARIFICATION

a. Design Considerations

The following is needed to design premium quality aluminum castings as primary structural components:

1. Development of reliable design property data in a manner acceptable for MIL-HDBK-5 use

2. Definition of quality assurance tests in applicable material specifications

3. Elimination of military requirements to use a casting factor

4. Design data for damage tolerance applications.

b. Foundry Considerations

An understanding is needed for the effect of processing variables on the properties of castings produced by various molding techniques. Quality assurance limits, inspection techniques, and process controls are needed to maintain a minimum property level in each casting routinely produced.

SECTION IV

SELECTION OF TEST CASTING AND DEVELOPMENT OF AN EVALUATION PROCEDURE

1. TEST CASTING SELECTION

A plate 3 inches by 10 inches with a thickness determined by the foundry was selected for foundry process evaluation. See Figure 1. Pattern costs and development effort were minimal for this configuration thereby allowing greater effort and cost to be expended toward developing program objectives.

2. PROCEDURE FOR EVALUATION OF PROCESS EFFECTS

The alloys included in this evaluation were A356, A357, and A201; the molding techniques were sand composite and shell investment. The manufacturing process effects selected for evaluation were melt chemistry, heat treatment response, solidification rate, and internal soundness. Results of other investigations have shown these effects to exhibit significant influence on casting properties. In this program each effect was independently evaluated to demonstrate the magnitude of each effect on the casting properties.

Standard reference plates were produced with each alloy and molding technique to establish a tensile property base. The optimum value for each variable and the level of tensile properties required in plates was defined and agreed upon by the foundry. A range of values for each variable was tested to demonstrate the importance of controlling the variable.

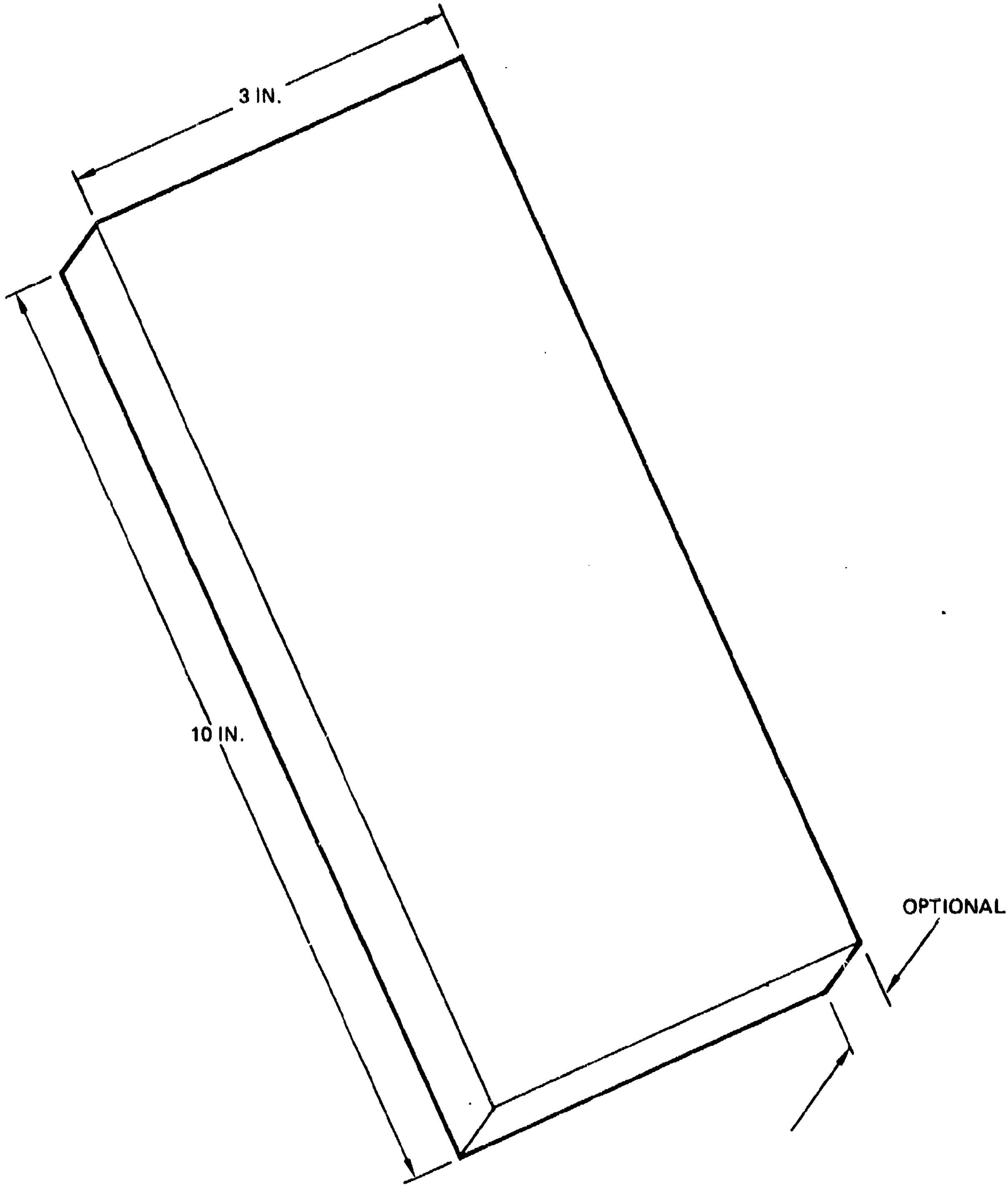


FIGURE 1. PLATE CASTING

The proposed foundry effort to produce test plates of each alloy and both molding techniques is described in detail in Appendix F.

Proposed minimum tensile properties for each alloy were:

1. A357-T6: 50 ksi ultimate strength
   40 ksi yield strength
   5 percent elongation

2. A356-T6: 38 ksi ultimate strength
   28 ksi yield strength
   5 percent elongation

3. A201-T7: 60 ksi ultimate strength
   50 ksi yield strength
   3 percent elongation

These values represent the highest level of strength requirements now contained in MIL-A-21180 for each alloy, although it may be unrealistic to apply these target values to investment molded castings.

It was proposed that to obtain the target properties, the standard reference plates should exhibit values within the following limits for each metallurgical variable:

Alloy and Temper	Melt Composition Limits*	DAS/Grain Size	Radiographic Quality	Yield Strength
A357-T6	% Mg: 0.57/0.62 % Fe: 0.13 max.	0.0015 inch max. DAS	Grade B min.	42 to 46 ksi
A356-T6	% Mg: 0.35/0.40 % Fe: 0.13 max.	0.0015 inch max. DAS	Grade B min.	32 to 36 ksi
A201-T7	% Mg: 0.30/0.35 % Cu: 4.65/4.85 % Ag: 0.55/0.65 % Mn: 0.30/0.40 % Fe: 0.05 max. %Si: 0.10 max.	0.0050 inch max. Grain Size	Grade B min.	55 ksi min.

*Remainder of composition to be within the limits specified in MIL-A-21180.

SECTION V

SURVEY AND SELECTION OF FOUNDRY PARTICIPANTS

The objective of this task was to survey potential foundry participants and select those who would best demonstrate the effect of process variables on casting properties. The molding techniques considered were shell investment and sand composite. Alloys to be included in this task were A356, A357, and A201.

Inquiries were sent to all foundries included in the earlier survey which indicated an interest in participating in the program. Bids were received from sand composite foundries of Hitchcock Industries, Magnesium Alloy Products Company, and V&W Castings Company. Investment foundries responding were Golden State, Arwood Corporation, and Cercast Inc. The foundries selected to participate were Hitchcock Industries for production of the sand composite plates of A356, A357, and A201 alloys, Cercast Inc. for production of A356 shell investment plates and Arwood Corporation for A357 and A201 shell investment plates.

As previously discussed, foundries employing other molding techniques were not considered since the majority of MIL-A-21180-type aluminum castings procured for airframe structure were found to be produced by either the shell investment or sand composite molding technique in the survey of airframe manufacturers.

SECTION VI

FOUNDRY PROCESS DESCRIPTION AND TEST PLAN

1. INTRODUCTION

The objective of this portion of the program was to evaluate the effect of the manufacturing variables that are involved in the production of structural aircraft aluminum castings. The variables were evaluated with regard to their effects on the tensile properties of the castings. While variables of foundry processing have been previously evaluated, this investigation was unique because (1) the quality of the material was maintained at near optimum level and, (2) the effect of each variable was individually evaluated in a systematic manner. With this level of quality, the properties of the castings are very responsive to relatively minor changes of processing compared to lesser quality castings wherein the effects of the variables are often masked out.

This investigation provided a direct comparison of the effects of processing on the tensile properties of three alloys using two different manufacturing methods. More than 700 tensile tests were conducted to evaluate the effect of process variations. The results of these evaluations were used to develop procurement specification requirements for airframe structural castings and provide generic manufacturing process control technology to the foundry industry. This information was also applied to the development and production of test castings which were evaluated to obtain statistically based design properties for inclusion in MIL-HDBK-5.

2. MANUFACTURING PROCESS DESCRIPTION AND QUALIFICATION

The foundries involved in this phase of the program were airframe casting suppliers with proven capabilities in the production of aluminum castings to the premium quality requirements of MIL-A-21180.

The foundries selected for participation were Hitchock Industries, Minneapolis, Minnesota, for production of sand composite test plates in all three alloys; Cercast Inc., Montreal, Canada, for production of shell investment test plates in alloy A356; and Arwood Corporation, Tilton, New Hampshire, for production of shell investment test plates in alloys A357 and A201.

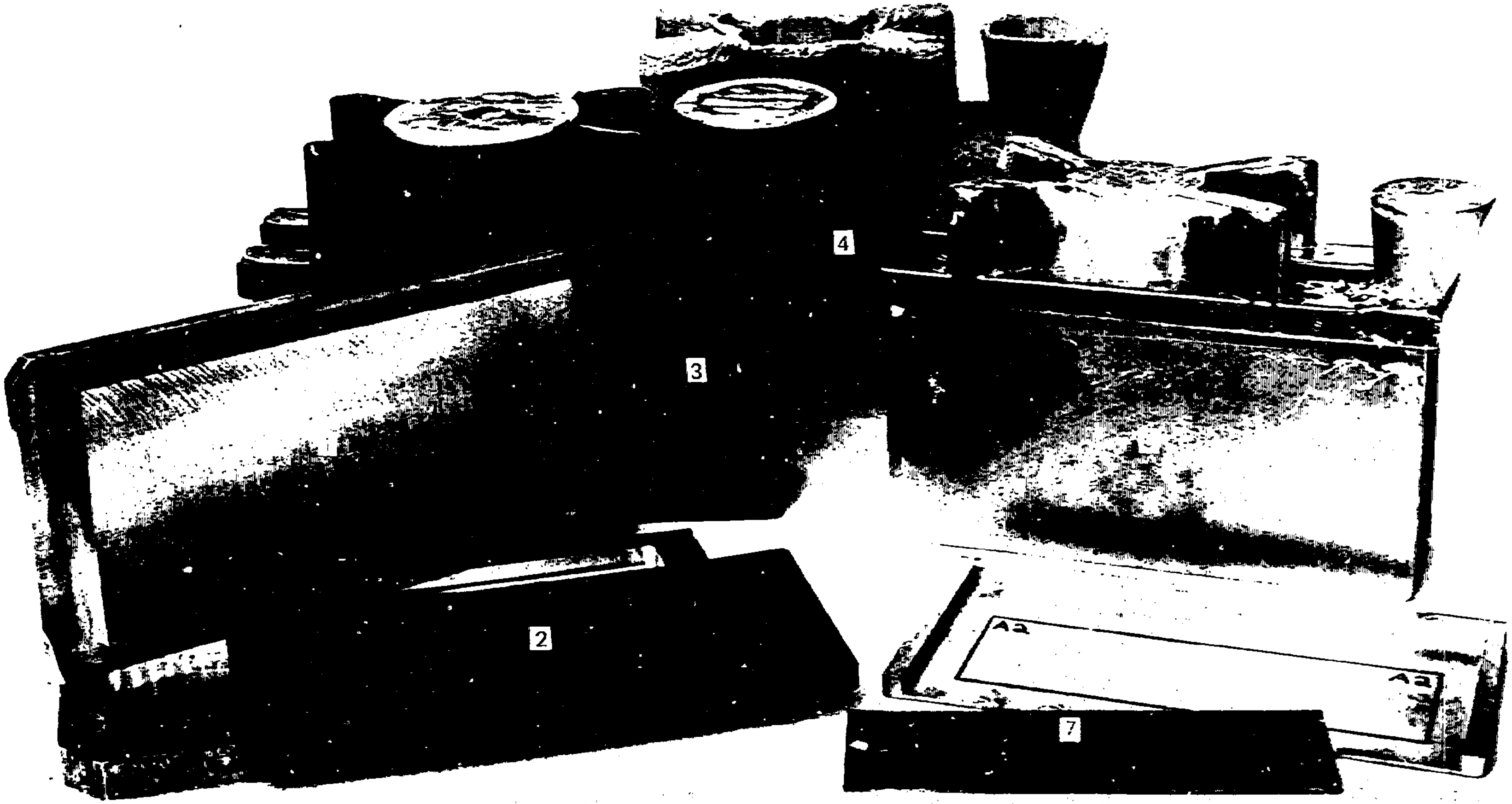
a. Cercast Foundry Procedure for Shell Investment Casting A356-T6 Test Plate

(1) Molding Procedure

The metal was cast in a hot investment shell. The following steps were taken to produce the shell: A metal die (Item 1 in Figure 2) was injected with wax to form the wax pattern (Item 2). The wax pattern was removed from the die and attached to a wax casting and risering assembly (Item 3). The wax assembly was then coated with two coats of refractory slurry with a colloidal silica binder, followed by five coats of slurry with an ethyl silicate binder. A shell thickness of 0.2 inch was thus obtained (Item 4). The coated assembly was then dewaxed in an autoclave using superheated steam that quickly removed most of the wax. The shell was then cured in an oven. This firing also removed any remaining traces of wax.

(2) Melting

Virgin aluminum alloy A356 ingots were melted in a silicon carbide crucible and held at 1350F. Flux was added, and the oxides were skimmed off the surface of the melt. The chemical content was adjusted to ensure a magnesium content of 0.36 pecent and a titanium content of 0.17 percent. The melt was then degassed with a dry 95/5 nitrogen freon mixture until gas-free, based on a reduced pressure test at 0.2 inch of mercury. After the oxides were skimmed off again, a chemical analysis was made to verify that all elements were within the specified composition limits.



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1	METAL DIE	3	WAX ASSEMBLY	5	CAST ASSEMBLY	7	TEST PLATE
2	WAX PATTERN	4	SHELL MOLD	6	CAST PLATE SECTION		

FIGURE 2. ASSEMBLY OF PROCESS TOOLING AND PRODUCTS

(3) Pouring

The investment shell was heated to 1000F in an oven and then removed and the metal, heated to 1320F, was poured into the mold. The end of the mold opposite to the sprue was raised so that the mold was poured in slightly tilted position.

(4) Cleaning

After the molten metal had solidified and cooled sufficiently so that it could be handled, the shell was vibrated off the casting. The gates and risers were removed by sawing and then finishing by grinding (Items 5, 6, and 7 in Figure 2.)

(5) Heat Treatment

The castings were solution heat treated at 1000F $\pm$ 5F for 18 hours, held at room temperature for 12 to 24 hours, then aged at 310F for 5 hours.

b. Arwood Foundry Procedure for Shell Investment Casting of A357-T6 and A201-T7 Test Plates

(1) Molding Procedures (Same for Both Alloys)

The metal mold (Item 1 of Figure 3) was injected with wax to form the wax pattern of the plate (Item 2). The wax pattern was attached to the gating and risering system to form a wax assembly (Item 3). Six coatings of refractory material were applied to the wax pattern assembly to form the mold (Item 4 of Figure 10). Between each coating, the assembly was submerged in a water-based colloidal-silica-slurry. The first two coatings were of fused silica, approximately 300 mesh, and the final four coatings were made with "Calamo 22" aluminum silicate, a much coarser material than the fused silica. Chopped fiberglass was added to the Calamo 22. The assembly was then dewaxed in an autoclave using 100 psi steam. The wax was melted out quickly to prevent it from expanding and cracking the shell. The shell was cured at 1200F for 4 hours and then cooled to room temperature.

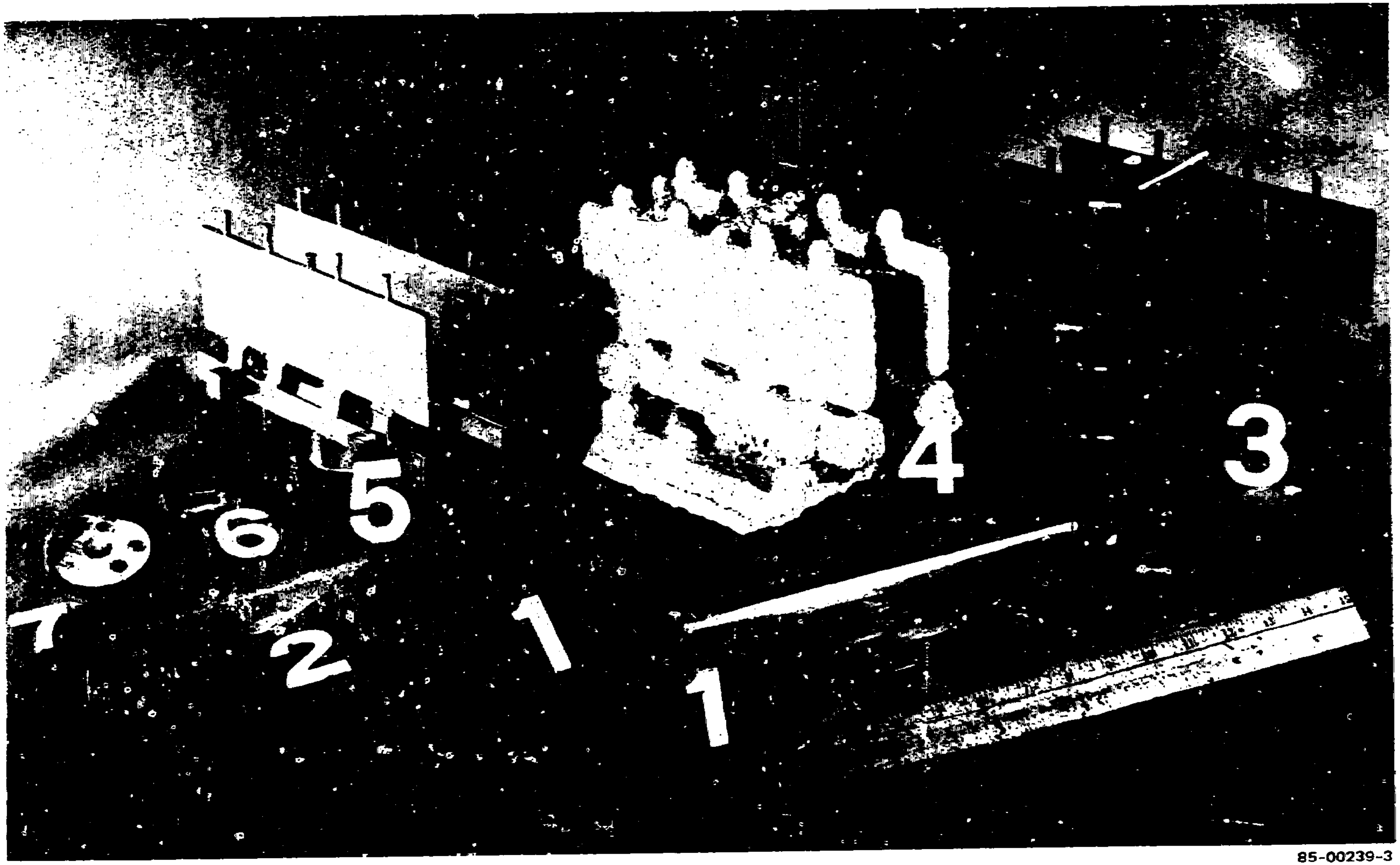

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FIGURE 3. ARWOOD SHELL INVESTMENT TOOLING AND PRODUCTS

(2) Melting

(a) Alloy A201

The 80-pound melt charge consisted entirely of ingot, melted in a 100-pound electric resistance furnace with a silicon carbide crucible. Grain refinement was accomplished with a 0.8-pound aluminum-titanium-boron (5 percent Ti - 1 percent B) waffle addition at 1300F melt temperature. Degassing followed, using 95 percent nitrogen and 5 percent Freon 12. Acceptance of the gas content was determined by the density of a test piece of metal solidified at one-tenth atmospheric pressure. the density sample is depicted (Item 6 in Figure 3). A sample of metal was taken from the melt for spectrographic analysis prior to pouring. The chemical sample is shown (Item 7 in Figure 3).

(b) Alloy A357

A 300-pound charge of ingots and returns (about 50 percent each) was melted in a silicon-carbide crucible in an electric resistance furnace. Grain refinement was accomplished using a 1.4-pound addition of aluminum titanium-boron (5% Ti - 1% B) at 1300F. Magnesium (0.05 pound) was then added, and the melt degassed with 95 percent nitrogen - 5 percent Freon 12 gas. A density sample, solidified at one-tenth atmospheric pressure, confirmed the removal of gas from the metal. A sample of metal was taken for spectrographic analysis prior to pouring.

(3) Pouring

Both alloys A357 and A201 were poured at a metal temperature of 1300F and with a pressure of 3-1/2 psi. Pressure was applied by introducing argon gas into the covered melting crucible. This forced the metal up the sprue and into the mold. The mold was placed over the crucible with the sprue extending down into the molten metal. The pouring weight of each mold was 3.25 pounds.

(4) Cleaning

The mold was vibrated to remove the major portion of the shell; then exposed to a jet of high velocity water to clean off the remaining refractory. The cleaned casting is shown in Item 5 of Figure 3. All gates and risers were stub cut, using a band saw, and then ground back to final dimension.

(5) Heat Treatment

(a) Alloy A201

The solution treatment consisted of 965F for 2 hours, increased to 990F for 16 hours, and followed by quenching in room temperature water. The plates were straightened in the as-quenched condition. Following a 12-hour delay at room temperature, they were aged at 370F for 5 hours.

(b) Alloy A357

The plates were solution heat-treated at 1000F for 12 hours, quenched in room temperature water, held for 12 hours at room temperature, and aged at 340F for 6 hours.

c. Hitchcock Foundry Procedure for Sand Composite Casting A357-T6, A356-T6, and A201-T7 Test Plates

(1) Molding Procedures

All alloys were cast in a cope and drag sand mold. The sand was bank sand, AFS 60, with 0.8-percent Pepset used as a binder. The core boxes used to make the mold haves are shown (Figure 4). The chills that were added to the mold halves (Figure 5) consisted of one brass chill (13 pounds) placed in the drag; one iron chill, 4 by 3 by 5/8 inch (2 pounds); and two iron chills, 2 3/4 by 5/8 by 1/2 inches (3 ounces), located in the cope half of the mold (Figure 6 shows their locations in the mold). Steel wool and two metal screens were added to the well of the down sprue as shown in the drag mold section (Figure 6). The mold halves were sprayed with a light coating of Pyroseal, then pasted and closed. Then metal was poured into the mold. The plate was then shaken loose from the mold and cleaned of molding sand. The plate with rigging attached is shown in Figure 7.

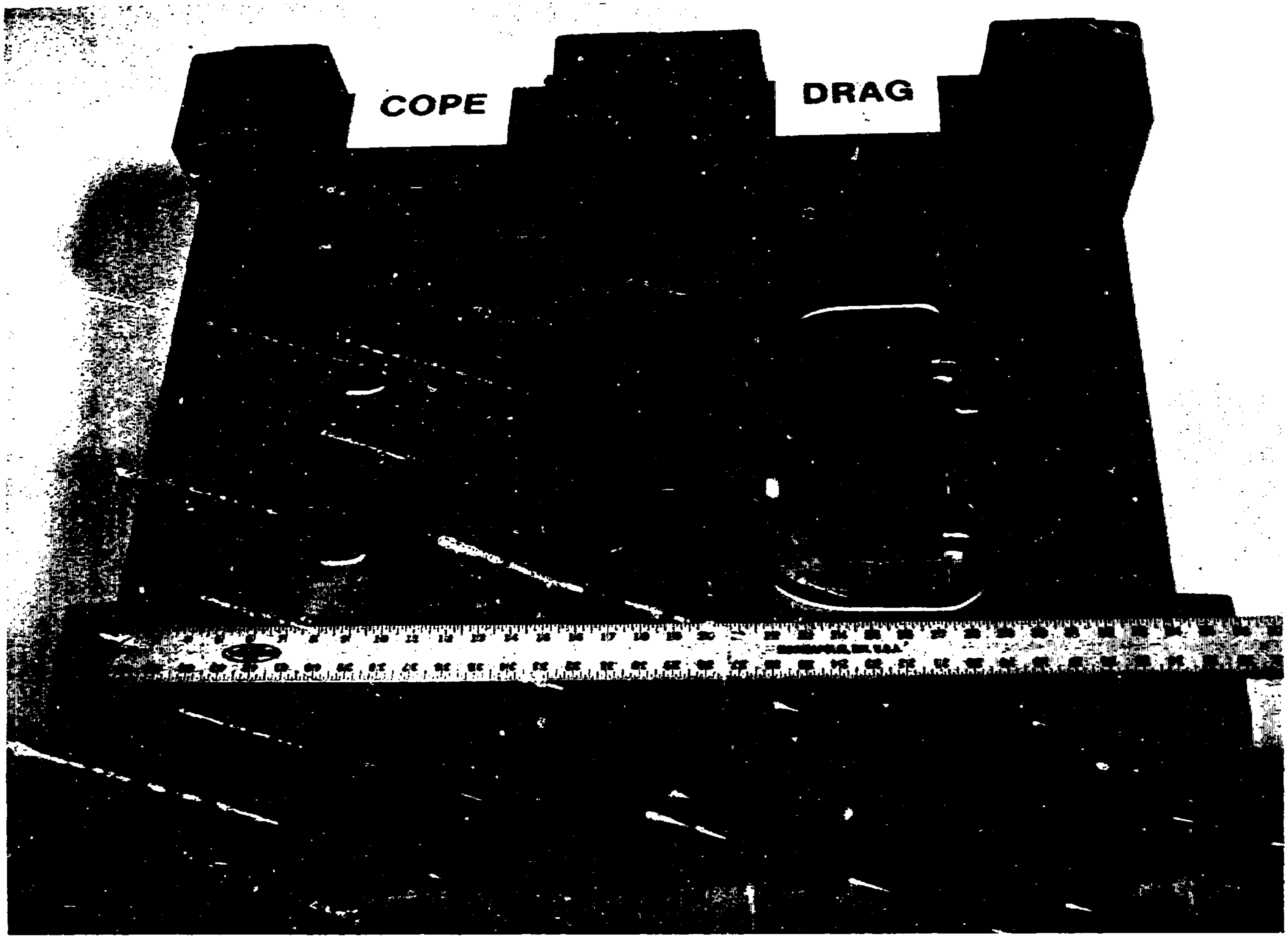

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FIGURE 4. CORE BOXES WITH PATTERNS USED FOR COPE AND DRAG MOLDS

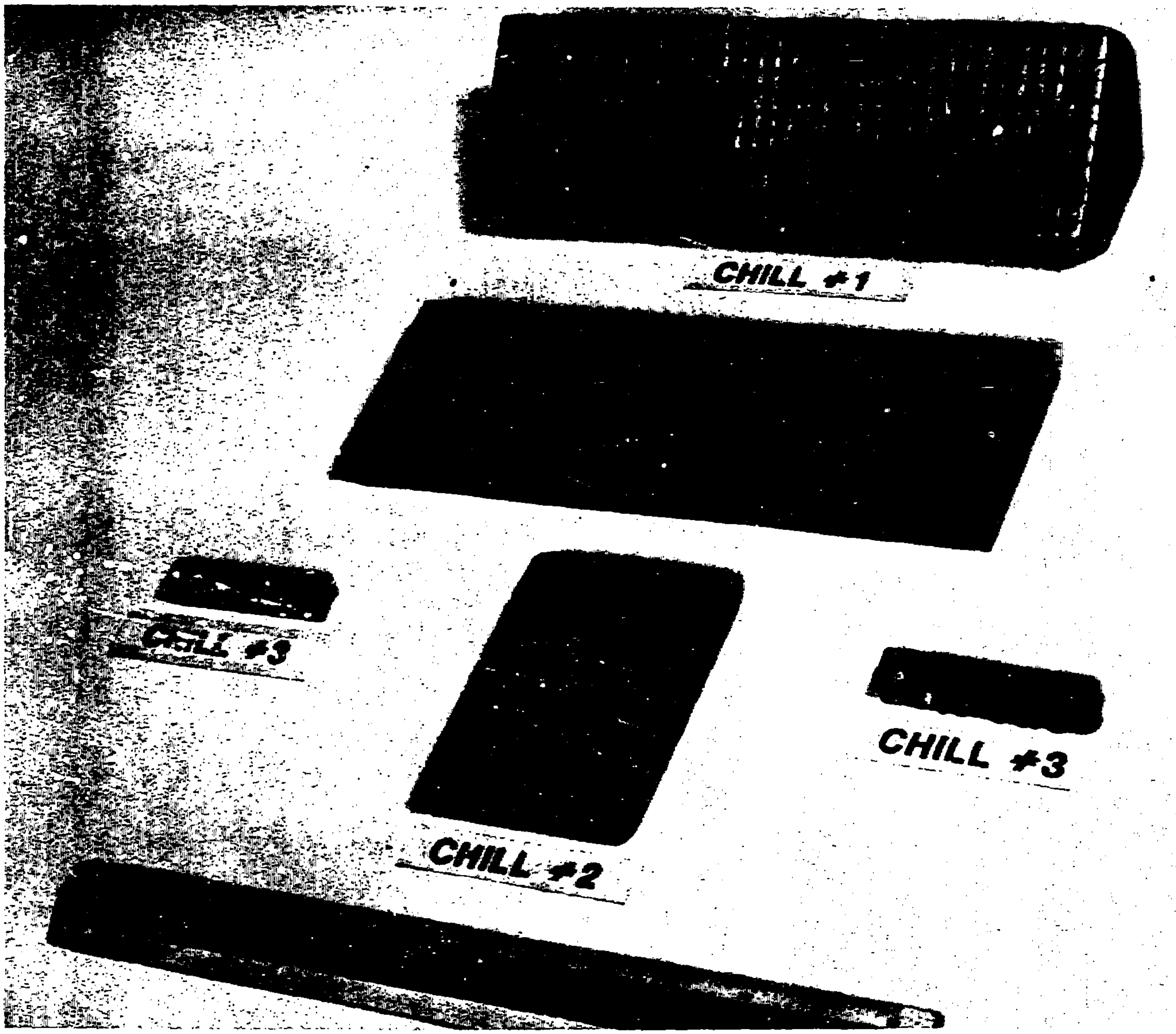

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FIGURE 5. CHILLS AND TEST PLATE

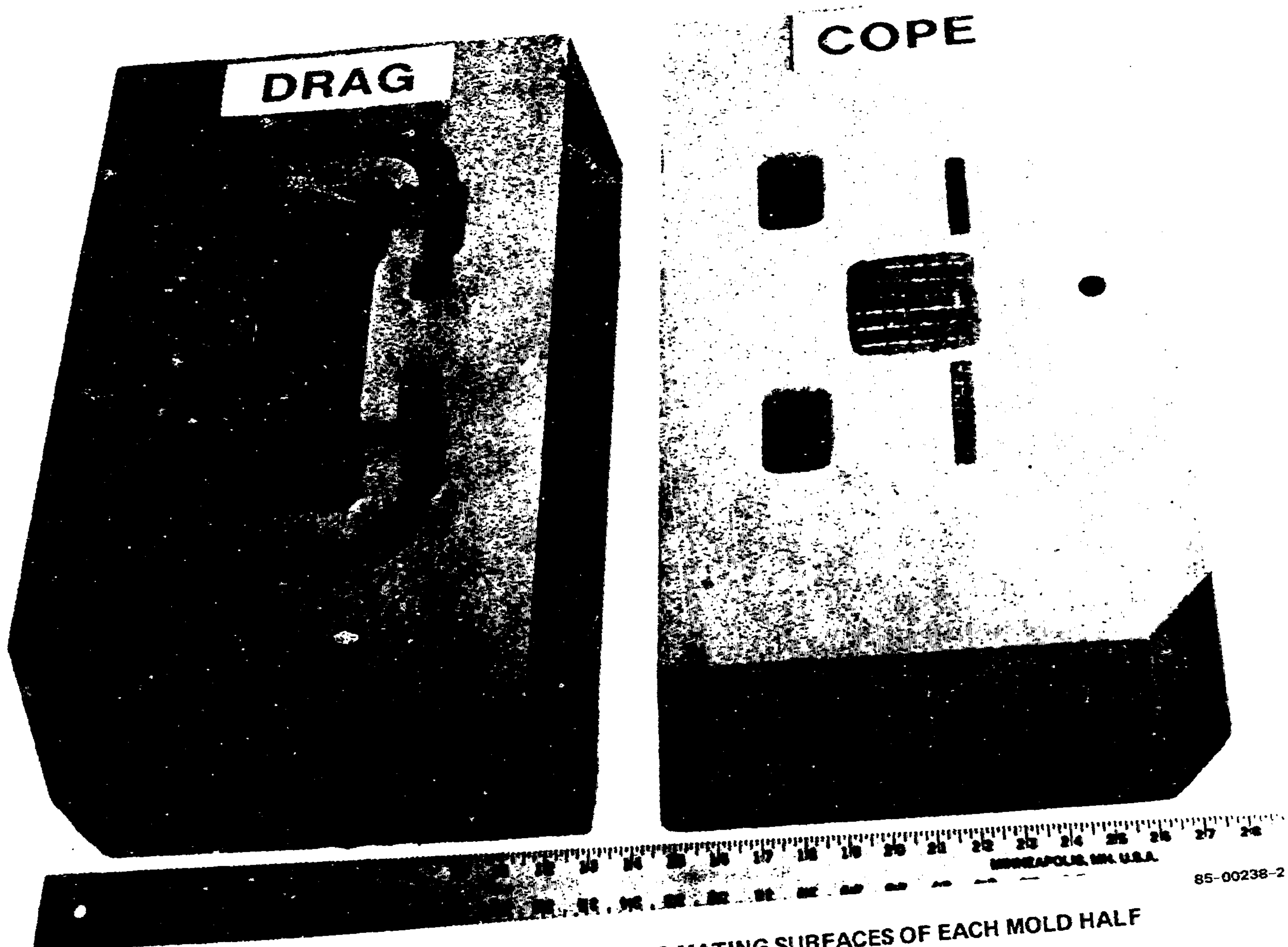


FIGURE 6. COPE AND DRAG MOLDS SHOWING MATING SURFACES OF EACH MOLD HALF

FIGURE 7. TEST PLATE WITH RIGGING ATTACHED

(2) Melting

All alloys were melted in a 1000-pound electric resistance-furnace using a silicon-carbide crucible. The charges were usually 60-percent ingot and 40-percent returns. Melts used for test plates were approximately 300 pounds. Typical ingot analyses were:

Elements, %	A356	A357	A201
Silicon	7.00	7.20	0.03
Iron	0.10	0.09	0.03
Copper	0.01	0.01	4.40
Magnesium	0.38	0.63	0.24
Titanium	0.12	0.10	0.21
Manganese			0.34
Silver			0.50
Beryllium		0.05	

Materials used for melt additions were:

1. Beryllium as beryllium-aluminum
2. Magnesium as magnesium ingot
3. Silicon as aluminum silicon ingot (25% Si)
4. Copper as copper shot
5. Manganese as aluminum manganese ingot (10% Mn)
6. Titanium and boron as titanium-boron wire
7. Silver as recovered silver from x-ray film

The melt was degassed by injecting a mixture of 90-percent nitrogen and 10-percent chlorine gas through a graphite lance into the metal. The metal was considered degassed when a sample, allowed to solidify under a vacuum of 2 to 4 inches of mercury, did not show any gas holes when sectioned and polished. After the metal was degassed, a spectrographic sample was taken from the melt and the composition was adjusted. A second gas check was made and, if satisfactory, the melt was raised to 1375F for pouring. Just prior to pouring, a final check of melt chemistry was made, and if acceptable, the melt was poured.

(3) Pouring

The metal was dipped from the melting crucible and poured at 1375F into the mold at room temperature using a steel ladle coated with refractory Insulkotz R-20.

(4) Clean Up

After the casting was shaken out of the mold, the gates were cut off and the casting was identified and rough-ground for heat treatment.

(5) Heat Treatment

All plates were loaded in a vertical position (on the 10-inch edge) and one inch apart in a basket. The plates were solution-treated in a gas-fired furnace in the following manner:

1. Alloy A356: 18 hours at 1000F
2. Alloy A357: 18 hours at 1010F
3. Alloy A201: 2 hours at 975F, 18 hours at 985F

The plates were quenched in 40F water using a 7-to-11-second maximum quench delay. After a delay at room temperature of 12 to 24 hours, the plates were artificially aged as shown below:

1. Alloy A356: 8 hours at 310F
2. Alloy A357: 8 hours at 325F
3. Alloy A201: 5 hours at 370F

Plates were evaluated for the following:

(a) Brinell Hardness (10mm Ball, 500 kg load)
(b) X-ray Quality
(c) Microstructure
(d) Tensile Strength

d. Foundry Process Qualification

Each foundry submitted test plates to demonstrate the tensile property capabilities of their processes. The target minimum tensile properties of the standard plates manufactured by both processes in each alloy were

as follows:

	A357-T6	A356-T6	A201-T7
Ultimate tensile strength (ksi) min.	50	38	60
Yield strength (ksi) min.	40	28	50
Elongation (%) min.	5	5	3

The tensile properties of the standard test plates are listed in Tables 1 through 6.

Although with more refined procedures these processes could have been improved to obtain higher tensile properties, they were considered acceptable to demonstrate the effects of variables on the casting properties.

TABLE 1. TENSILE PROPERTIES OF A357-T6 SAND COMPOSITE STANDARD PLATES (3/4 INCH THICK)

	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (%)	Hardness (HRE)
	48.0	39.9	5.0	96
	49.5	42.8	4.0[1]	98
	49.1	41.5	5.2	96
	47.4	40.0	4.8	95
	50.3	41.5	7.0	96
	48.4	39.9	6.1	96
	48.3	41.6	5.1	96
	48.6	40.7	5.8	95
	49.5	41.9	6.2	96
Range:	47.4/50.3	39.9/42.8	4.8/7.0	95/98
Average:	48.8	41.1	5.6	96
Target Min:	50.0	40.0	5.0	

NOTE: 1. Broke outside the middle half of the gage length of the specimen.

Comments: DAS range (inch): 0.0009 - 0.0012 (plate surface)
Mg (%): 0.58 - 0.59
Fe (%): 0.08 - 0.12

TABLE 2. TENSILE PROPERTIES OF A356-T6 SAND COMPOSITE STANDARD PLATES (3/4 INCH THICK)

	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (%)	Hardness (HRE)
	43.9	32.7	8.0	89
	42.8	32.5	6.4	88
	43.3	32.7	7.4	89
	41.3	31.8	5.7	87
	42.5	32.4	7.2	87
	42.0	31.9	6.5	84
	43.3	32.3	7.4	87
	42.4	32.4	6.2	89
	39.8	32.5	4.3	90
	38.1	32.4	4.4	90
Range:	38.1/43.9	31.8/32.7	4.3/8.0	84/90
Average:	41.9	32.4	6.3	88
Target Min:	38.0	28.0	5.0	

Comments: DAS range (inch): 0.0009 - 0.0011 (plate surface)
Mg (%): 0.38
Fe (%)· 0.10 - 0.12

TABLE 3. TENSILE PROPERTIES OF A201-T7 SAND COMPOSITE STANDARD PLATES (3/4 INCH THICK)

	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (%)	Hardness (HRE)
	62.1	57.4	4.4	77
	69.7	59.1	4.1	77
	64.7	59.8	5.7	77
	63.0	59.0	4.2	79
	66.6	62.0	5.4	80
	63.6	59.2	4.4	79
	65.9	61.5	4.7	77
	64.9	60.5	4.9	78
	65.5	60.6	4.9	79
	64.6	60.8	4.0	71
Range:	62.1/69.7	57.4/62.0	4.0/5.7	71/80
Average:	65.1	60.0	4.8	77
Target Min:	60.0	50.0	3.0	

Comments: Grain Size (inch): 0.0020 - 0.0030 (plate surface)
Mg (%): 0.31 - 0.35
Cu (%): 4.63 - 4.65
Ag (%): 0.53 - 0.56
Si (%): 0.04
Fe (%): 0.01 - 0.05

TABLE 4. TENSILE PROPERTIES OF A357-T6 SHELL INVESTMENT STANDARD PLATES (3/16 INCH THICK)

	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (%)	Hardness (HRE)
	48.6	40.0	7.4	95
	47 2	40.0	4.9	93
	48.6	40.0	6.6	94
	48.8	40.4	7.0	95
	47.1	39.8	5.4	92
	47.9	39.8	6.7	93
	47.7	40.2	5.1	94
	48.6	40.1	4.7	96
	49.0	41.8	4.3	96
	50.0	40.7	5.5	96
Range:	47.1/50.0	39.8/41.8	4.3/7.4	92/96
Average:	47.3	40.3	5.8	94
Target Min:	50.0	40.0	5.0	

Comments: DAS range (inch): 0.0012 - 0.0016 (plate surface)
Mg (%): 0.51
Fe (%): 0.10 - 0.13

TABLE 5. TENSILE PROPERTIES OF A356-T6 SHELL INVESTMENT STANDARD PLATES (1/10 INCH THICK)

	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (%)	Hardness (HRE)
	41.7	30.9	8.4	86
	40 7	30.4	7.2	86
	41.9	32.1	(7.3)(G)	87
	40.4	31.7	6.3	86
	42.4	33.2	7.3	88
	41.8	32.7	7.7	87
	42.4	33.6	(8.2)(F)	87
	41 5	31.9	6.5	88
	42.5	33.9	7.1	92
	42.0	32.8	6.0	86
Range:	40.4/42.5	30.4/33.9	6.0/8.4	86/92
Average:	41.7	32.3	7.1	87
Target Min:	38.0	28.0	5.0	

(G) - Specimen broke outside the gage length

(F) - Fracture surface of specimen shows a flaw

Comments: DAS range (inch): 0.0018 - 0.0025 (plate surface)

Mg (%): 0.36

Fe (%): 0.04

TABLE 6. TENSILE PROPERTIES OF A201-T7 SHELL INVESTMENT STANDARD PLATES (3/16 INCH THICK)

	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (%)	Hardness (HRB)	Electrical Conductivity (% IACS)
	63.5	56.6	6.8	73	32.7
	64.0	56.3	9.8	75	31.8
	62.8	55.8	7.9	74	32.5
Range:	62.8/64.0	55.8/56.6	6.8/9.8	73/75	31.8/32.7
Average:	63.4	56.2	8.6	74	32.3
Target Min:	60.0	50.0	3.0		

Comments: Grain Size (inch): 0.0027 - 0.0030 (plate surface)

Mg (%): 0.23

Cu (%): 4.37

Ag (%): 0.41

Si (%): 0.03

Fe (%): 0.01

3. PLATE TEST PLAN AND INSPECTION PROCEDURE

The types and quantities of the tests used in evaluation of the cast plates are shown (Tables 7 and 8). The foundries x-rayed each plate to ensure that a Grade B radiographic quality was obtained and an analysis was made of each melt to ensure conformance to composition requirements. These results were forwarded with each shipment of test plates. Upon receipt of the plates at Northrop, a plate of each group was evaluated for surface DAS (A356 and A357) or grain size (A201), one plate of each melt was analyzed for chemical composition, and the foundry radiograph of each plate was reviewed. Hardness and conductivity measurements were taken prior to excision of the tensile specimen. If these evaluations were acceptable, the location of the tensile specimen was indicated on the plate. After removal of the tensile specimens, each specimen was x-rayed again to validate the radiographic quality as Grade B or better in accordance with MIL-C-6021 specification requirements. If acceptable, the specimen was tested.

Each group of plates contained at least three plates processed in the same manner as the original standard reference plates. These plates were used as baseline properties for the group.

TABLE 7. INSPECTION PLAN FOR SHELL INVESTMENT CAST PLATES

ALLOY, FOUNDRY, TASK NUMBER & VARIABLE	NUMBER OF PLATES	FOUNDRY TESTS		NORTHROP TESTS[a]							
		CHEMISTRY (MELT)	X-RAY	CHEMISTRY (PLATE)	X-RAY	EXTERNAL: DAS	EXTERNAL: GRAIN SIZE	TENSILE	ELECTRICAL CONDUCTIVITY	HARDNESS	MICRO
A356, CERCAST											
1. NONE	10	1	10	1	10	10	–	10	10	10	2
2. SOLIDIFICATION RATE	9	1	9	1	9	9	–	9	9	9	3
3. HEAT TREATMENT	48	1	48	1	48	48	–	48	48	48	2
4. SOUNDNESS	18	2	18	1	18	18	–	18	18	18	6
5. CHEMISTRY	24	8	24	2	24	24	–	24	24	24	4
SUBTOTAL	109	13	107	6	109	109	–	109	109	109	17
A357, ARWOOD											
1. NONE	10	1	10	1	10	10	–	10	10	10	2
2. SOLIDIFICATION RATE	9	1	9	1	9	9	–	9	9	9	3
3. HEAT TREATMENT	48	1	48	1	48	48	–	48	48	48	2
4. SOUNDNESS	18	2	18	1	18	18	–	18	18	18	6
5. CHEMISTRY	36	12	36	4	36	36	–	36	36	36	8
SUBTOTAL	121	17	121	8	121	121	–	121	121	121	21
A201, ARWOOD											
1. NONE	10	1	10	1	10	–	5	10	10	10	5
2. GRAIN SIZE	18	4	18	1	18	–	6	18	6	6	6
3. HEAT TREATMENT	48	1	48	1	48	–	4	48	24	24	4
4. SOUNDNESS	18	2	18	1	18	–	6	18	4	4	6
5. CHEMISTRY	63	21	63	5	63	–	10	63	20	20	10
SUBTOTAL	157	29	157	9	157	–	31	157	64	64	31
TOTAL	387	59	387	23	387	230	81	387	298	298	69

[a]NOTE: MINIMUM NUMBER OF TESTS PER TASK

TABLE 8. INSPECTION PLAN FOR SAND COMPOSITE CAST PLATES

ALLOY, FOUNDRY, TASK NUMBER & VARIABLE	NUMBER OF PLATES	FOUNDRY TESTS		NORTHROP TESTS[a]							
		CHEMISTRY (MELT)	X-RAY	CHEMISTRY (PLATE)	X-RAY	EXTERNAL: DAS	EXTERNAL: GRAIN SIZE	TENSILE	ELECTRICAL CONDUCTIVITY	HARDNESS	MICRO
A356, HITCHCOCK											
1. NONE	10	1	10	1	10	10	–	10	10	10	2
2. SOLIDIFICATION RATE	9	1	9	1	9	9	–	9	9	9	3
3. HEAT TREATMENT	48	1	48	1	48	48	–	48	48	48	2
4. SOUNDNESS	18	2	18	1	18	18	–	18	18	18	6
5. CHEMISTRY	24	8	24	2	24	24	–	24	24	24	4
SUBTOTAL	109	13	107	6	109	109	–	109	109	109	17
A357, HITCHCOCK											
1. NONE	10	1	10	1	10	10	–	10	10	10	2
2. SOLIDIFICATION RATE	9	1	9	1	9	9	–	9	9	9	3
3. HEAT TREATMENT	48	1	48	1	48	48	–	48	48	48	2
4. SOUNDNESS	18	2	18	1	18	18	–	18	18	18	6
5. CHEMISTRY	36	12	36	4	36	36	–	36	36	36	8
SUBTOTAL	121	17	121	8	121	121	–	121	121	121	21
A201, HITCHCOCK											
1. NONE	10	1	10	1	10	–	5	10	10	10	5
2. GRAIN SIZE	18	4	18	1	18	–	6	18	6	6	6
3. HEAT TREATMENT	48	1	48	1	48	–	4	48	24	24	4
4. SOUNDNESS	18	2	18	1	18	–	6	18	4	4	6
5. CHEMISTRY	63	21	63	5	63	–	10	63	20	20	10
SUBTOTAL	157	29	157	9	157	–	31	157	64	64	31
TOTAL	387	59	387	23	387	230	81	387	298	298	69

[a]NOTE: MINIMUM NUMBER OF TESTS PER TASK

SECTION VII

EVALUATION OF TEST PLATES

In this task, cast plates were produced to demonstrate the effects of manufacturing process variables on casting tensile properties.

The effects were determined for alloys A357-T6, A356-T6, and A201-T7 produced by both the shell investment and the sand composite processes. The purpose of this effort was to determine their relative importance in the production of aircraft structural quality castings. This information is needed to support the development of procurement specification requirements that will provide the user with a means of determining castings of an acceptable quality with a high degree of reliability, and to provide a technological base for the foundry metallurgist to use in the evaluation and development of production techniques for structural airframe cast configurations.

Although these variables were evaluated in previous investigations, they were not subjected to the systematic evaluation that they were in this study which involved materials of near-optimum quality produced in commercial foundries. The results of each variable are shown on a graph for easy evaluation. Each primary variable was divided into several secondary variables. These were independently varied so that their effects on tensile properties could be demonstrated. Each variable of each alloy and each molding method was represented in triplicate plates. The plates were approximately three inches wide and ten inches long. Thickness of the plates varied by process and foundry. All sand composite plates of each alloy were 3/4-inch thick; shell investment A357 and A201 plates were approximately 3/16-inch thick; and the A356 shell investment plates were approximately 1/10-inch thick. The thickness was selected by the foundries at their discretion to provide consistent high quality.

The primary and secondary variables were:

Primary Variable	Secondary Variable
Composition	
A357 Alloy	Magnesium content
	Iron content
A356 Alloy	Magnesium content
	Iron content
A201 Alloy	Silicon content
	Iron content
	Magnesium content
	Copper content
	Silver content
Heat Treatment	
All Alloys	Solution time
	Quench water temperature
	Delay time at room temperature
	Artificial aging time
Solidification Rate	
A356 and A357 Alloys	DAS
A201 Alloy	Grain size
Radiographic Quality	
All Alloys Grade A-D	Gas porosity
	Shrinkage sponge
	Dross

All the plates were cast using production equipment. This did not permit laboratory control of each situation. Although it was desirable to minimize variations within each group of "standard" conditions, so only one condition of the process varied, this was accomplished with varying degrees of success. Some abnormalities are evident in the results.

1. ALLOY A357 SAND COMPOSITE AND SHELL INVESTMENT PLATES

a. Composition

The melt composition was varied by changing the magnesium, iron, and beryllium content. Magnesium combines with silicon to form $M_{g2}Si$, which precipitates during artificial aging to strengthen the alloy. Iron is an impurity that combines with aluminum and silicon to form needles of $FeSiAl_5$, which embrittles the structure and therefore is undesirable. Beryllium has been reported to provide two beneficial effects: It preferentially oxidizes before the magnesium to form BeO, thereby reducing the loss of magnesium from the melt, and it also modifies the shape of the $FeSiAl_5$ needles to the nodular form $BeFeSiAl_5$, reducing the embrittling effect. Beryllium-iron combinations were investigated to determine if beryllium would increase the ductility of alloys with high iron content. The melt composition was varied in the following manner:

MIL-A-21180 Specification Requirement (%)	Target Values	Melt Composition (%) Sand Composite	Shell Investment
0.40/0.70	0.40	0.41	0.40
Magnesium	0.50	0.52	0.49
	0.60	0.57	0.60
	0.70	0.70	0.70
0.20 Iron	0.05	Not obtained	Not obtained
Maximum	0.10	0.10	0.08
	0.15	Not obtained	0.15
	0.20	0.17	Not obtained
0.04/0.07	0.05Be+0.10Fe	0.02Be+0.10Fe	0.06Be+0.08Fe
Beryllium	0.05Be+0.20Fe	0.02Be+0.24Fe	0.06Be+0.15Fe
	0.25Be+0.10Fe	0.09Be+0.10Fe	0.22Be+0.08Fe
	0.25Be+0.20Fe	0.09Be+0.18Fe	0.22Be+0.17Fe

(1) Magnesium

The strength of shell investment molded plates was significantly improved with increased magnesium content. Ductility of both sand composite and shell investment molded plates was significantly reduced with increased magnesium content. Most results of other investigations agreed with these findings. (References 1, 2, and 3). The results of the sand composite molded plates with 0.58 and 0.70 percent of magnesium, are questionable. The more likely trend is represented in the shell investment plate information (Compare Figures 8 and 9).

(2) Iron

It has been reported that an increase of iron content reduces ductility. (References 1, 3, 4, and 5). This investigation verified the effect of iron on the sand composite molded plates, however, the ductility of the shell investment plates did not change with increased iron content. Possibly this was due to the lower levels of ductility in the investment cast material. The strength of plates produced by both sand composite and shell investment mold methods was not significantly affected by increasing the iron content (Figures 10 and 11).

(3) Beryllium

The benefit of beryllium to the alloy was not evident in this investigation. Various additions of beryllium to melts of low to high iron content (within the specification range) did not result in a significant improvement in tensile properties of plates produced by either the sand composite or shell investment molding method (Figures 12 and 13). The beneficial effect of beryllium that has been reported, presumably have occurred in a material with a coarser microstructure. (References 4 and 6).

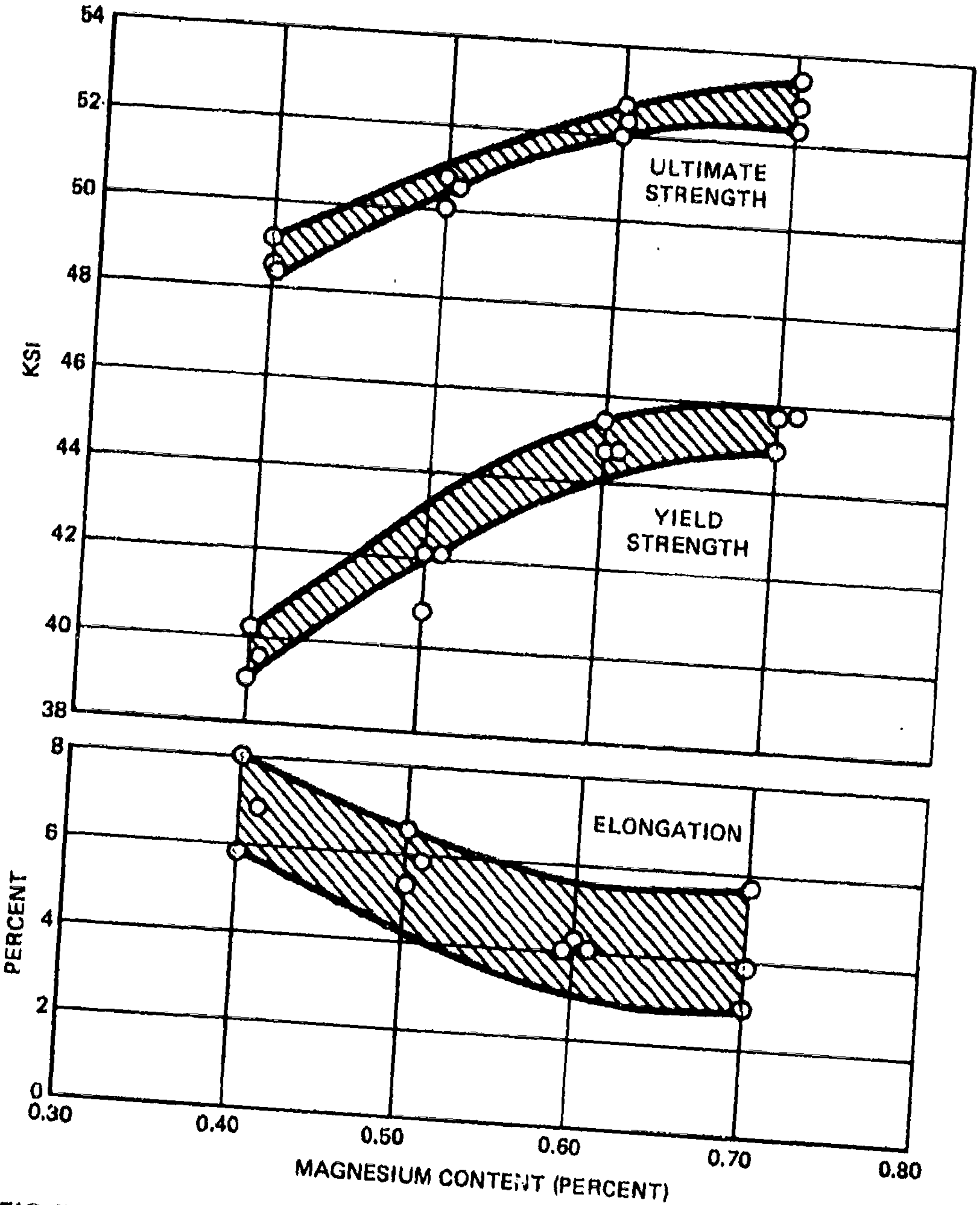


FIGURE 8. EFFECT OF MAGNESIUM CONTENT ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A357-T6

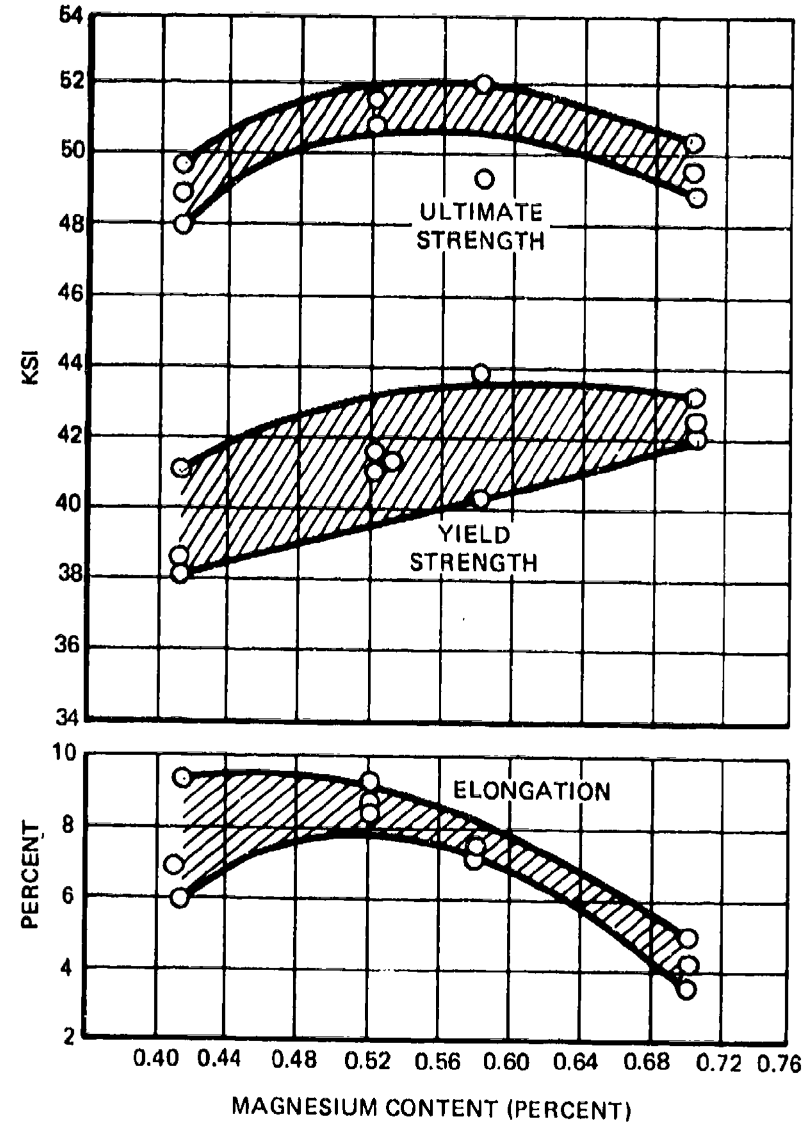


FIGURE 9. EFFECT OF MAGNESIUM CONTENT ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A357-T6

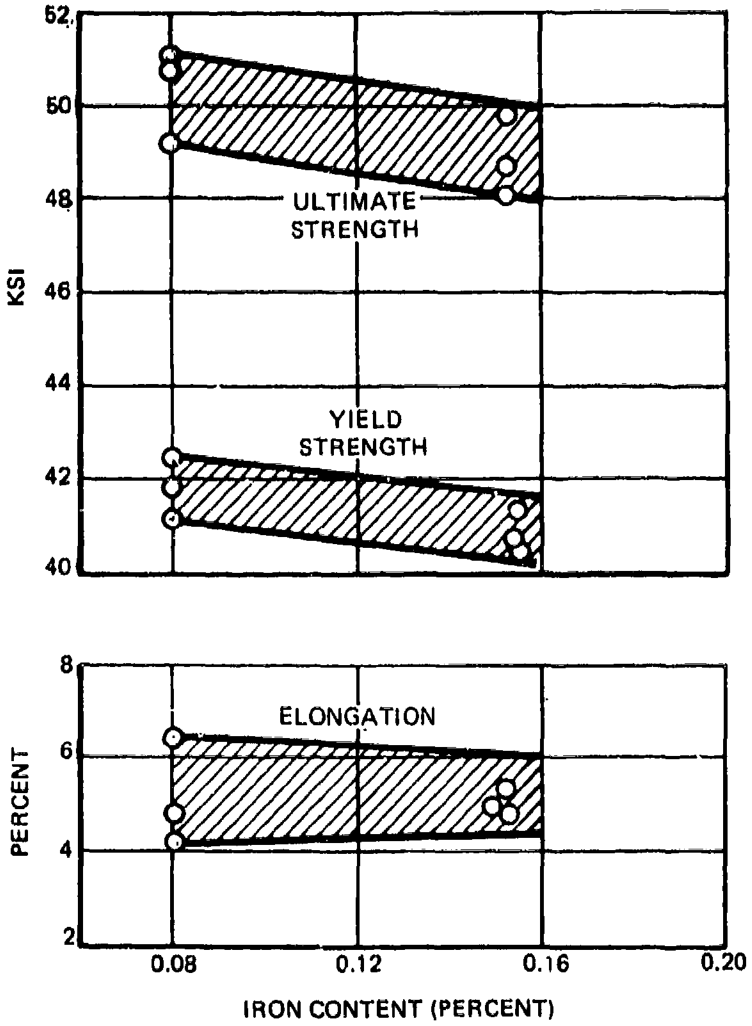


FIGURE 10. EFFECT OF IRON CONTENT ON THE TENSILE PROPERTIES OF SHELL INVESTMENT CAST A357-T6

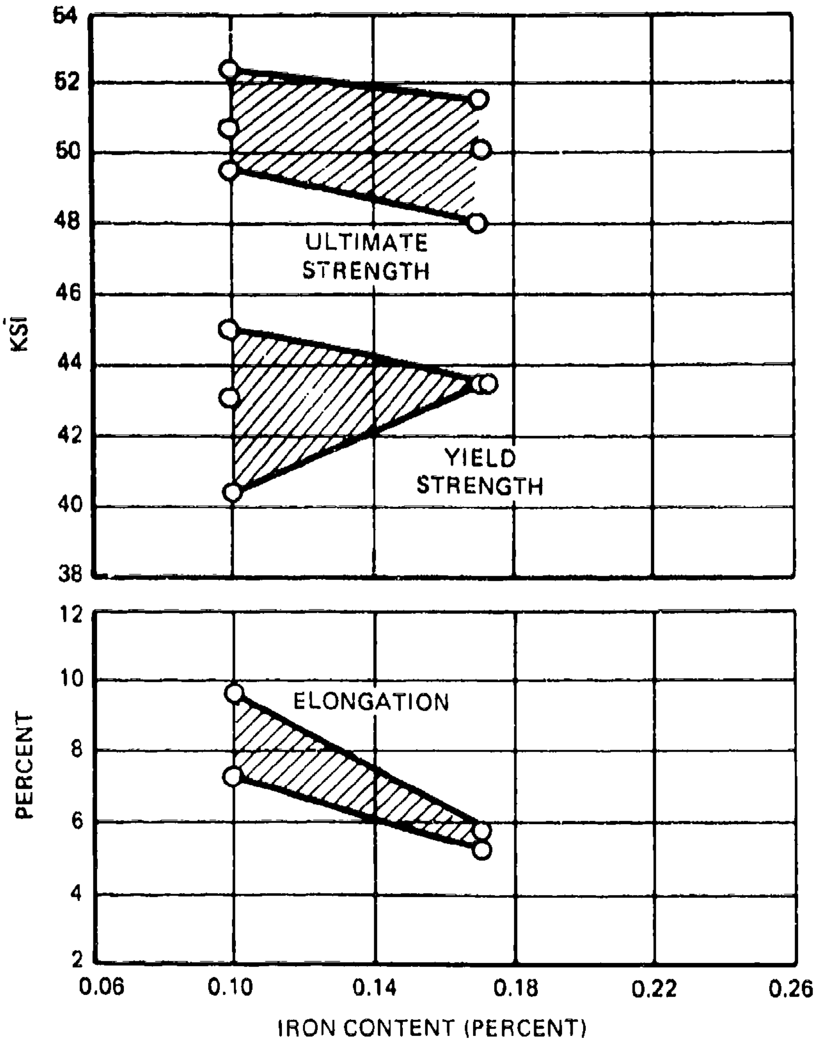


FIGURE 11. EFFECT OF IRON CONTENT ON THE TENSILE PROPERTIES OF SAND COMPOSITE CAST A357-T6

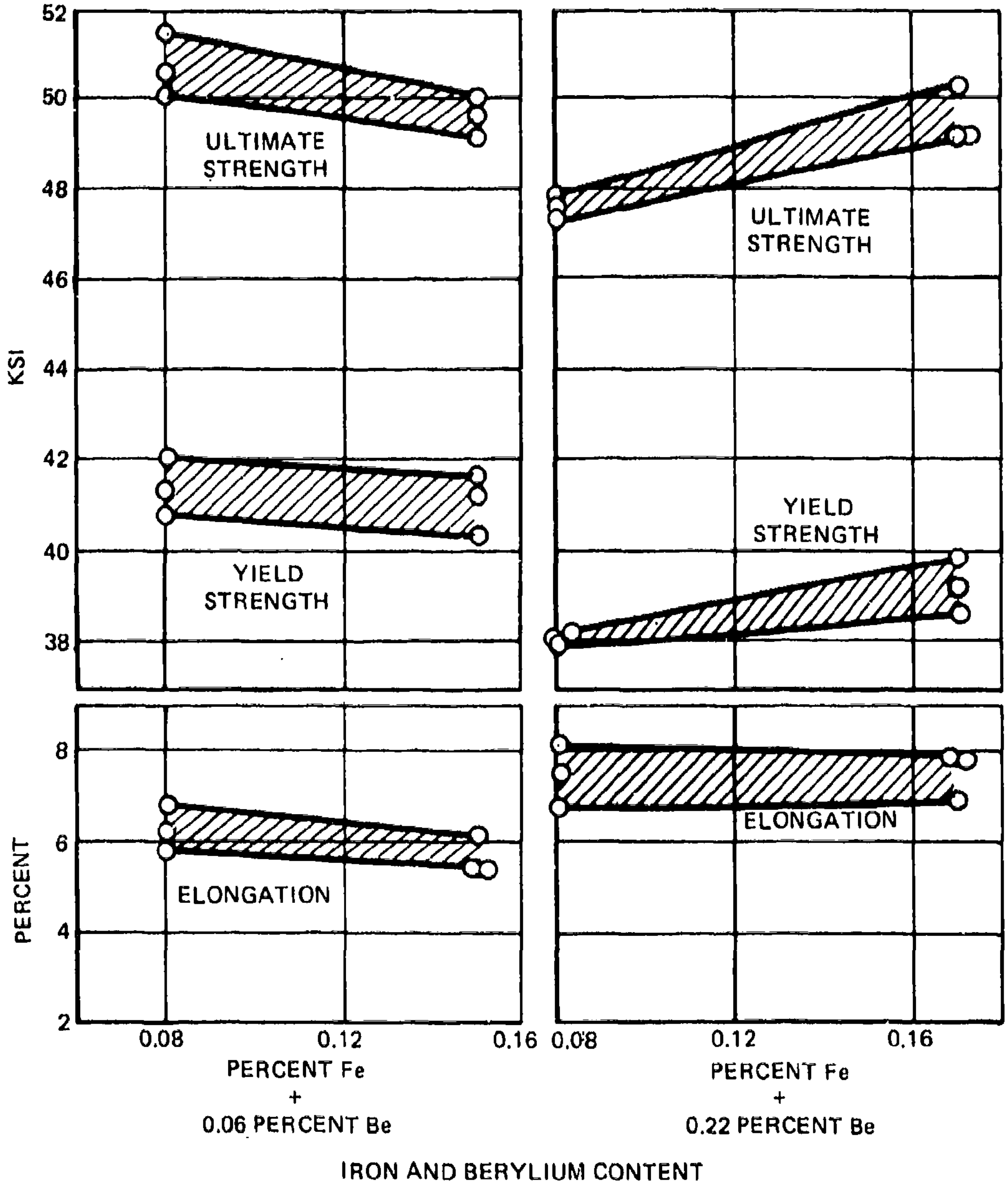


FIGURE 12. EFFECT OF IRON AND BERYLLIUM CONTENT ON THE TENSILE PROPERTIES OF SHELL INVESTMENT CAST A357-T6

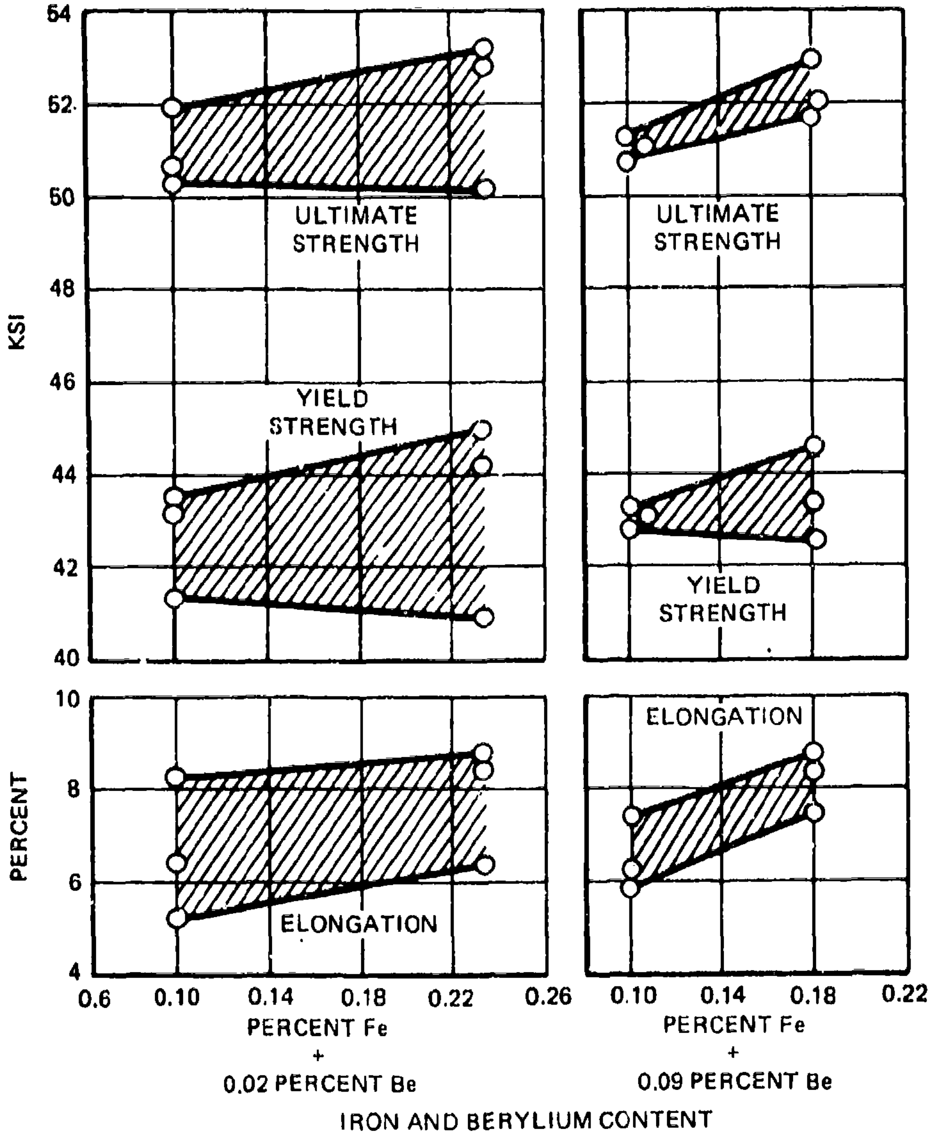


FIGURE 13. EFFECT OF IRON AND BERYLLIUM CONTENT ON THE TENSILE PROPERTIES OF SAND COMPOSITE CAST A357-T6

b. Heat Treatment

The following heat treatment process variables were included in this investigation:

1. Solution time
2. Quench water temperature
3. Delay time at room temperature
4. Artificial aging time.

The effects of each variable on the tensile properties of the plates produced by the sand composite and shell investment processes were determined and plotted to show trends. The differences in thickness of the sand composite plates (3/4 inch) and the shell investment plates (3/16 inch) in some instances, may have affected the results. The following heat treatment process was defined as standard for A357-T6 standard plates produced by each molding procedure:

Process Variable	Sand Composite Process	Shell Investment Process
Solution treatment	1010F, 18 hours	1000F, 12 hours
Quenchant	Water at 40F	Water at room temperature
Delay at room temperature	12 to 24 hours	12 hours
Artificial aging	325F, 6 hours	340F, 8 hours

(1) Solution Treatment Time

The solution times of six, twelve, and eighteen hours were evaluated. All plates were subsequently processed in accordance with the standard procedure to the T6 condition and tested. The results (Figures 14 and 15) indicate that a solution treatment time longer than six hours had very little effect on tensile properties. The ductility of the 3/4-inch thick sand composite molded plates improved, but the ductility of the 3/16-inch thick shell

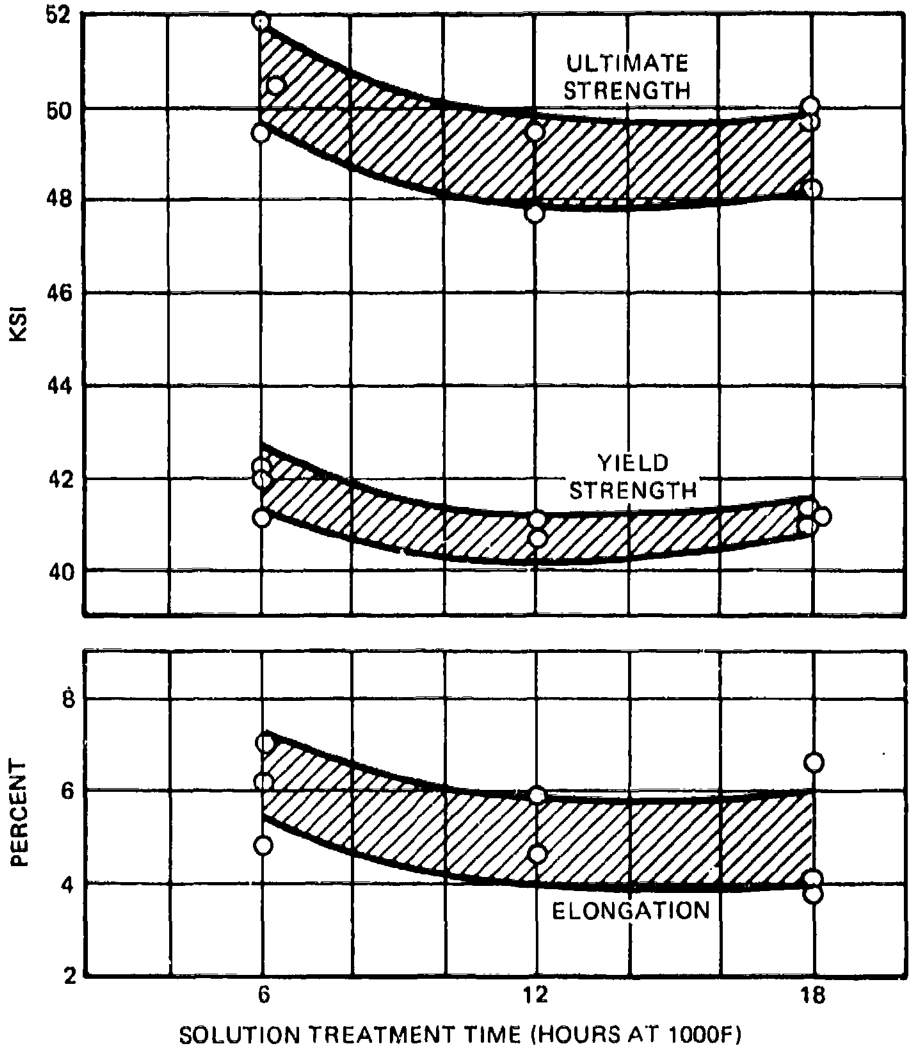


FIGURE 14. EFFECT OF SOLUTION TIME ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A357-T6

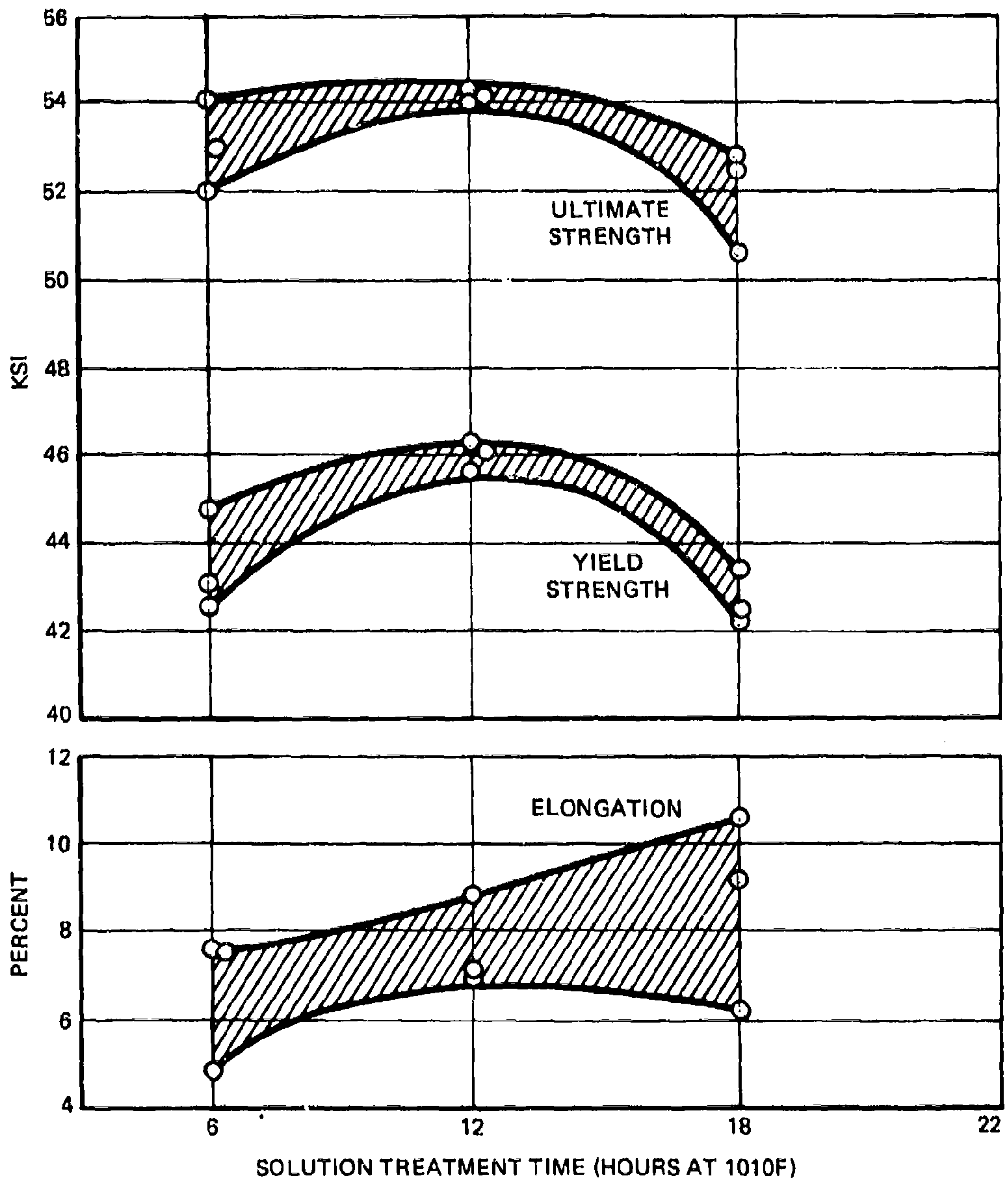


FIGURE 15. EFFECT OF SOLUTION TIME ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A357-T6

investment plates was slightly reduced. With a longer than six hours solution time, the strength values showed only a minor change.

(2) Quench Water Temperature

Quench water temperatures within the range of 40F to 212F were included in this investigation (Figures 16 and 17). All tensile properties were significantly reduced as the temperature of the water increased. The tensile properties of plates produced by the sand composite molding process and those produced by the shell investment molded process, showed similar effects. The properties of the thicker 3/4-inch sand composite plates were more severely reduced by quench water temperatures than the thinner 3/16-inch shell investment plates.

(3) Delay Period at Room Temperature

Delay periods of zero, one-half, one, and three days were included in the investigation. The only significant change in tensile properties occurred with the sand composite molded castings. The ductility was increased after a delay of one day. (Figures 18 and 19).

(4) Artificial Aging Time

Artificial aging times of zero, four, six, eight, and ten hours, were included in this investigation. Similar effects on tensile properties were found in the sand composite and shell investment plates. Both showed increased tensile strength and decreased ductility with longer aging times (Figures 20 and 21). The artificial age-hardening process is well known for precipitation hardening alloys. The hump in the elongation curve has already been reported (Reference 9) but the causes of this phenomenon have not been explained.

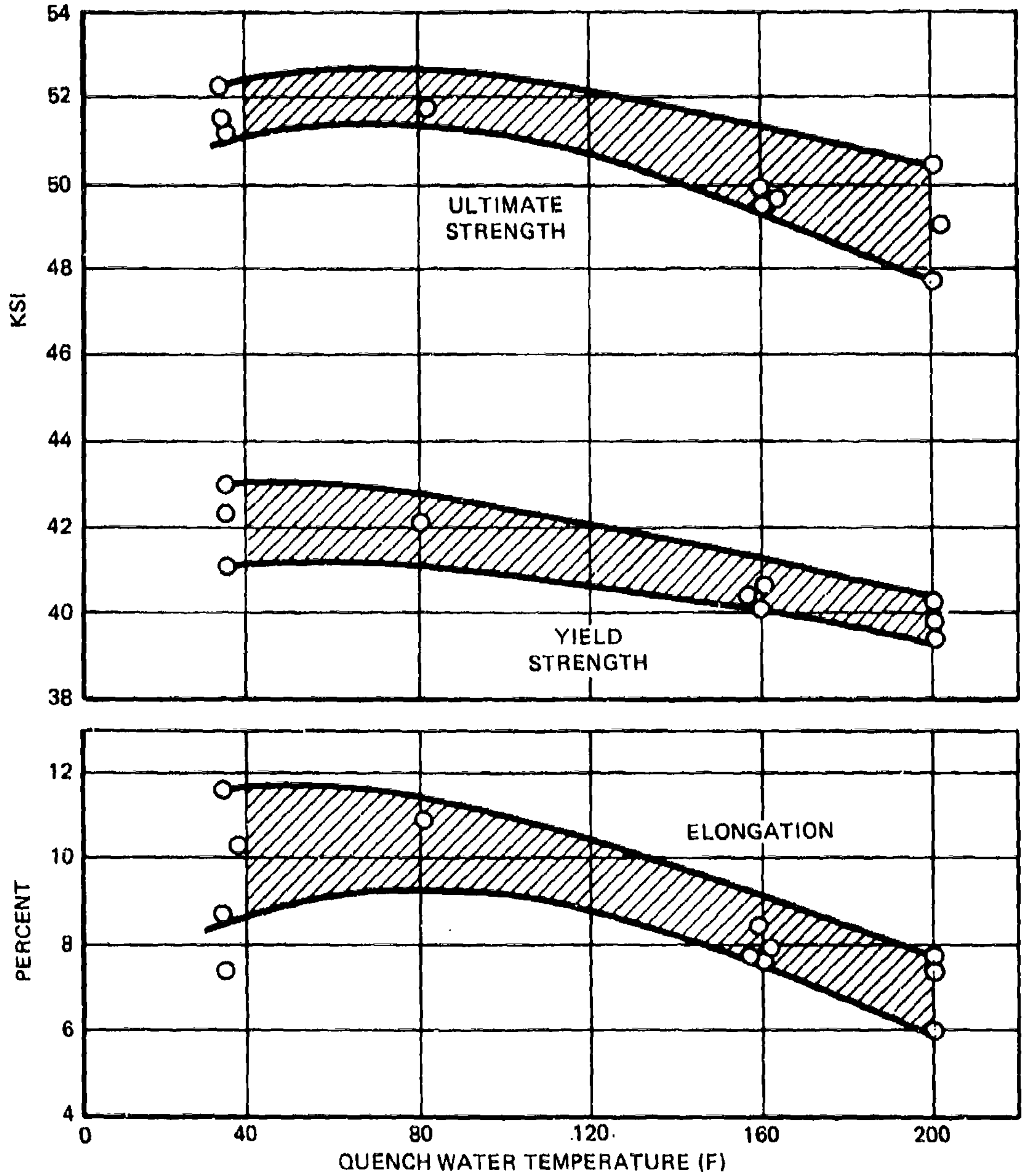


FIGURE 16. EFFECT OF QUENCH WATER TEMPERATURE ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A357-T6

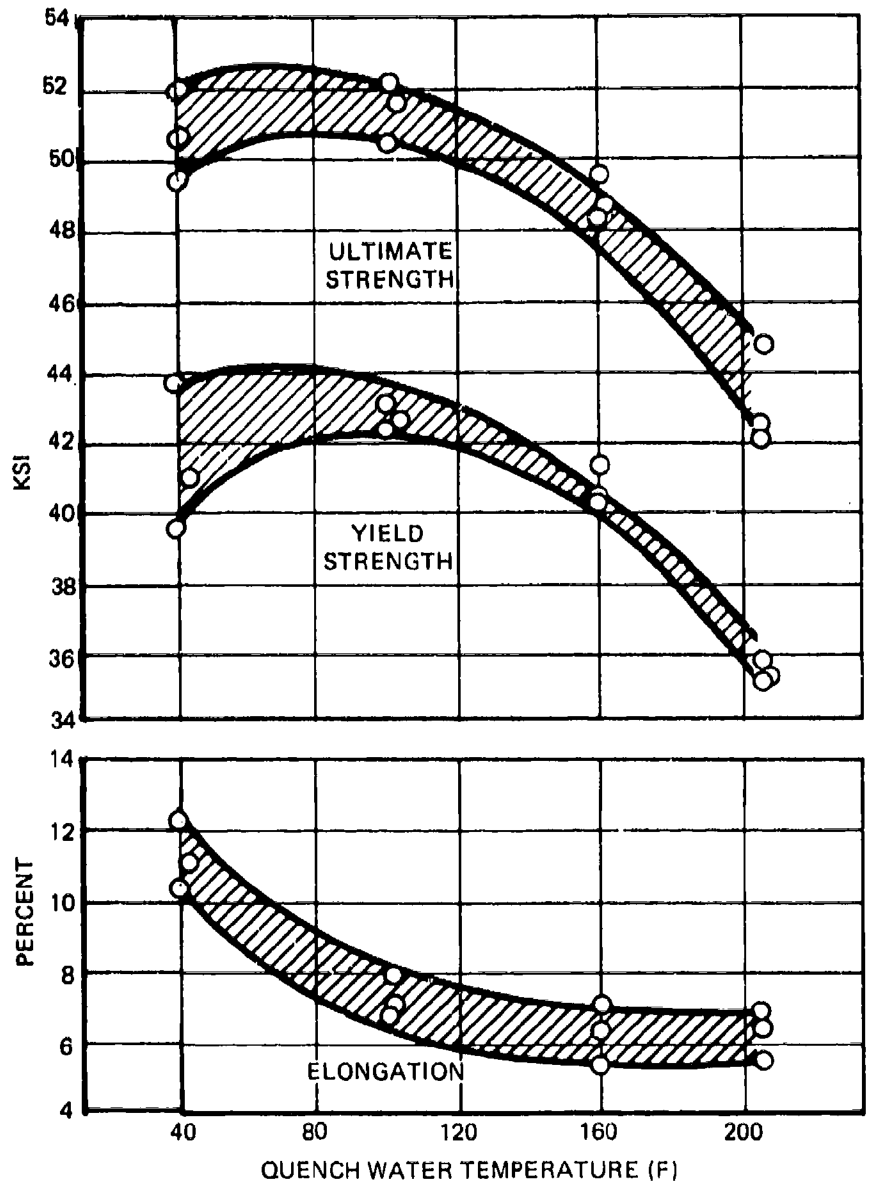


FIGURE 17. EFFECT OF QUENCH WATER TEMPERATURE ON THE TENSILE PROPERTIES OF SAND COMPOSITE CAST A357-T6

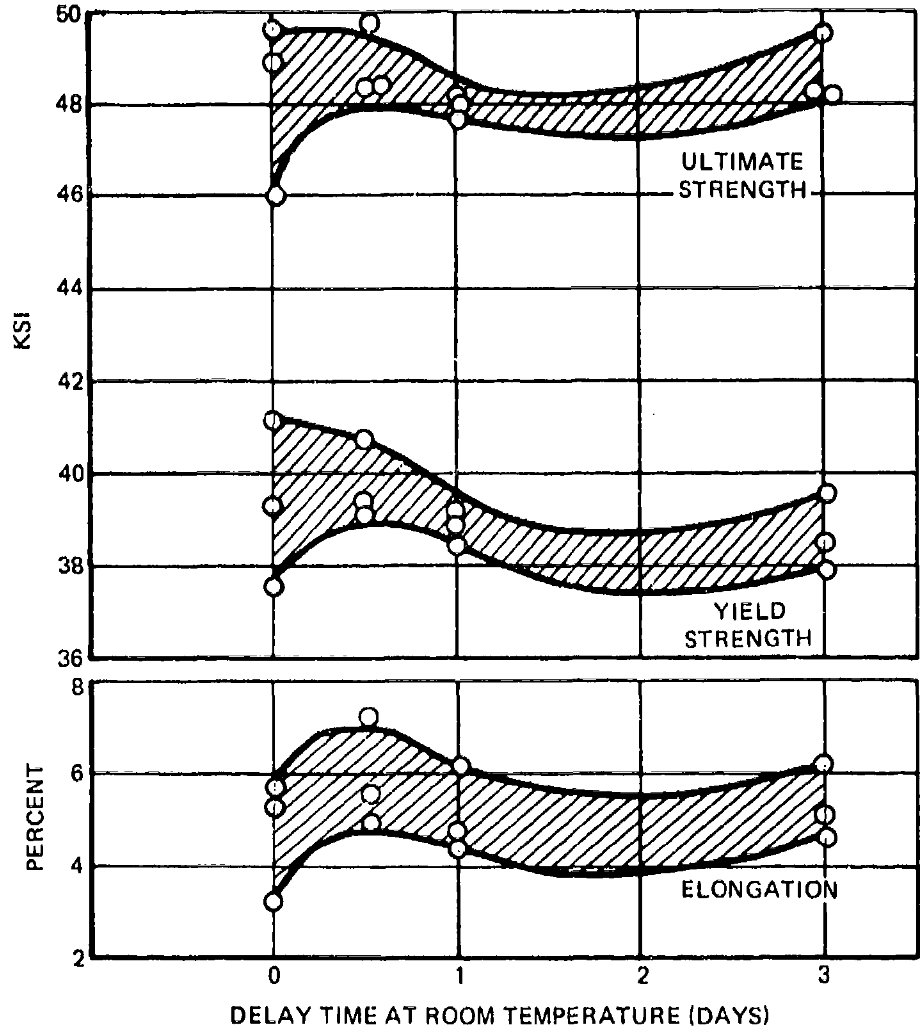


FIGURE 18. EFFECT OF DELAY TIME AT ROOM TEMPERATURE ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A357-T6

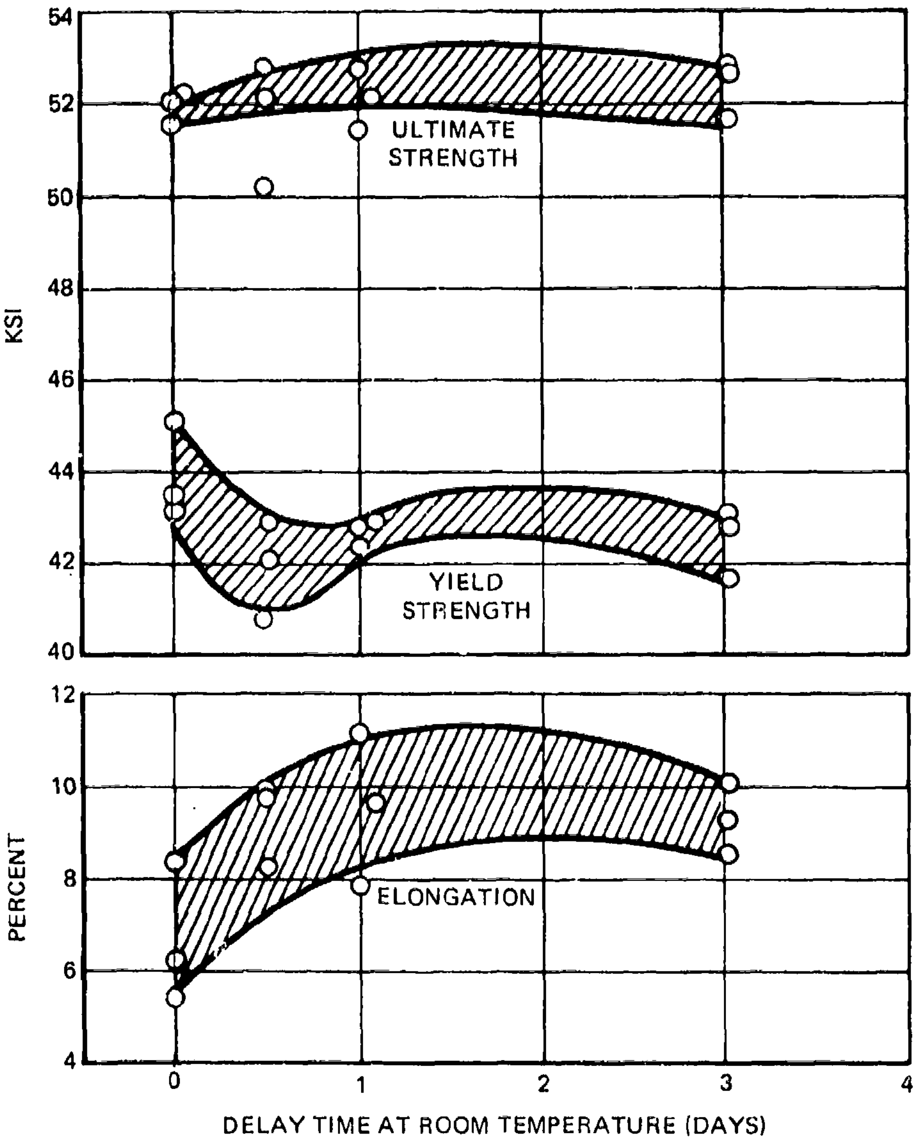


FIGURE 19. EFFECT OF DELAY TIME AT ROOM TEMPERATURE ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A357-T6

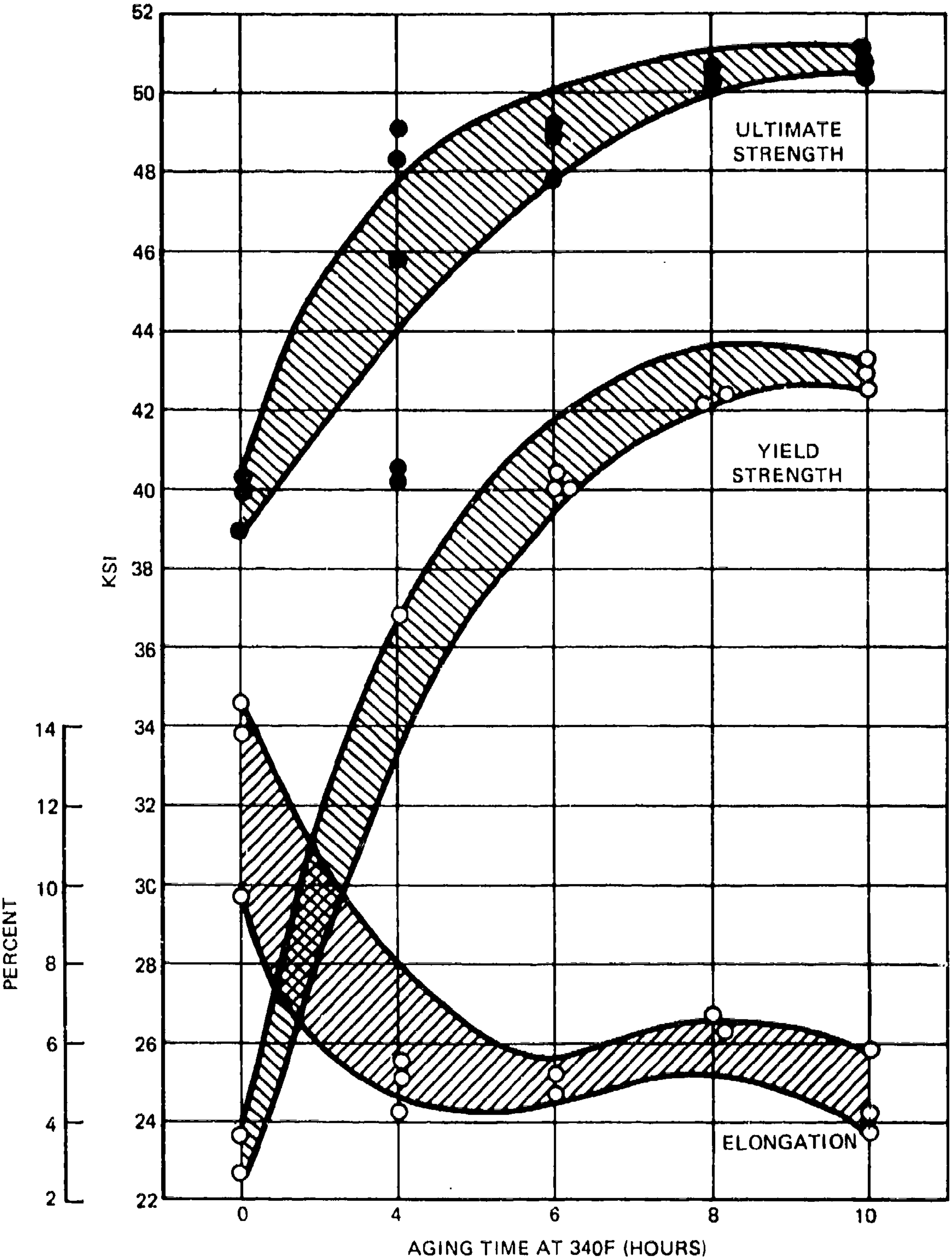


FIGURE 20. EFFECT OF AGING TIME ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A357-T6

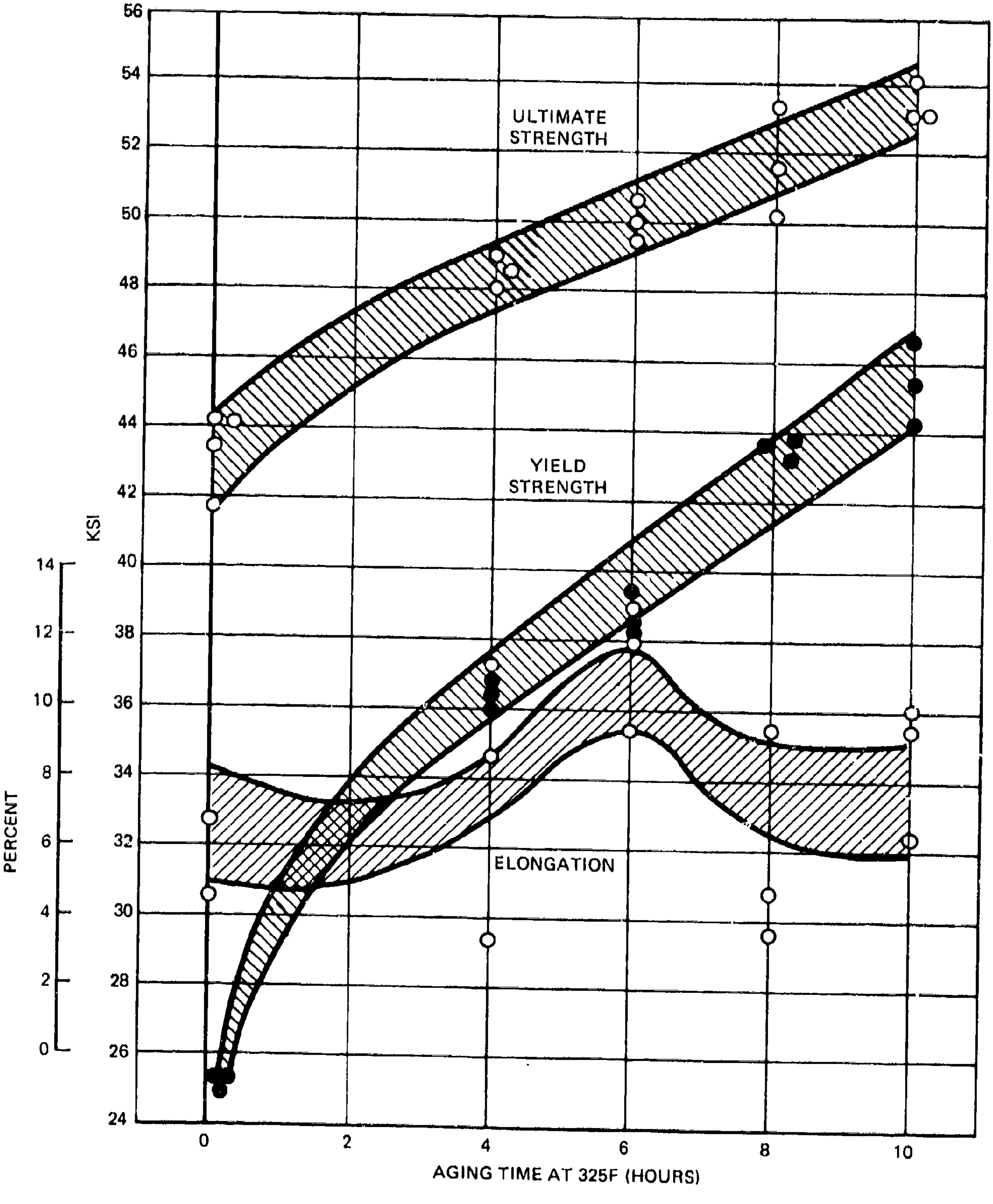


FIGURE 21. EFFECT OF AGING TIME ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A357-T6

c. Solidification Rate (as measured by DAS)

The effects of DAS on tensile properties has been well documented since it was reported by Spear and Gardner in the early 1960s (References 7, 8, 9, and 10). The changes in microstructure, resulting from various amounts of chilling used in the sand composite molds and mold temperature of the investment shells, correspond in a parallel manner. More chilling and lower mold temperatures produce a more refined structure and improved tensile properties, but less chilling and higher mold temperatures produce coarser structures and lower tensile properties (Figures 22, 23, 24 and 25).

d. Radiographic Quality

Two levels of radiographic quality were used in this investigation. The highest quality level was equal to, or better than, a Grade B per MIL-C-6021 (Figure 26). This quality represents the highest quality available for production castings and is usually required in high stress areas of premium quality castings. The lower quality investigated was a Grade C or D in accordance with MIL-C-6021 Grade definition. The types of radiographic defects evaluated were:

1. Dross (less dense material)
2. Shrinkage sponge
3. Porosity.

These types of defects are the most prevalent causes of radiographic rejection of MIL-A-21180 aircraft castings. The quality levels of each type of defect in each alloy was not reproduced in plates from each molding process. Radiographs of each plate depicted areas of unsoundness. Tensile specimens were obtained from these areas. Occasionally, after machining the specimen from the plates, the apparent radiographic quality was found to have changed, to a higher grade, and could not be used (Figure 27). The tensile properties of specimens, representing the two general levels of radiographic quality, were plotted by type of defect, alloy, and molding method (Figures 28 and 29). Each time the quality level decreased, the ultimate strength and

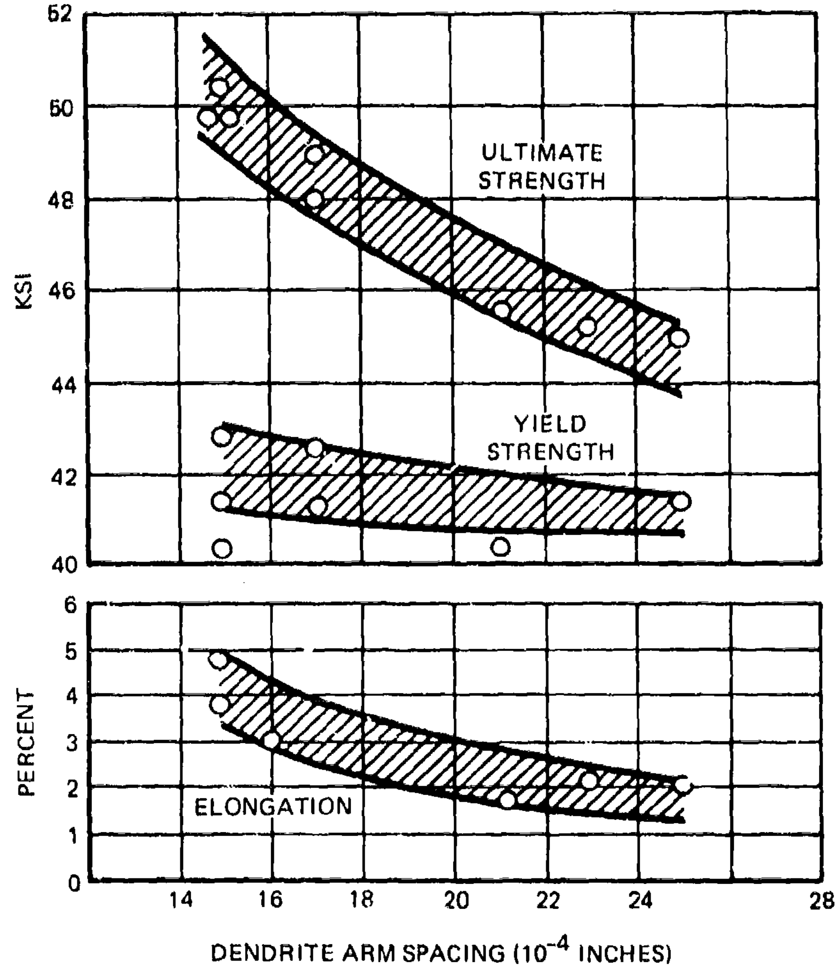


FIGURE 22. EFFECT OF DENDRITE ARM SPACING ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A357-T6

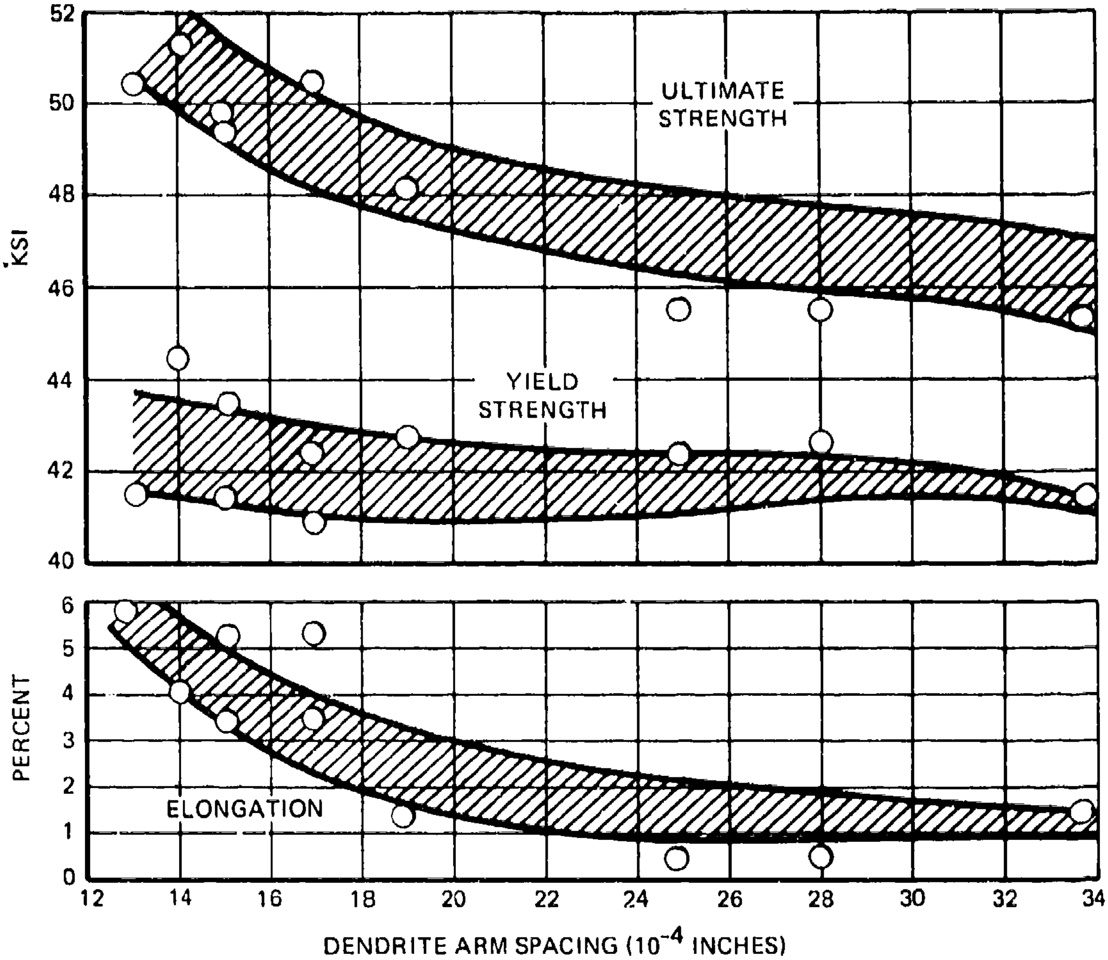
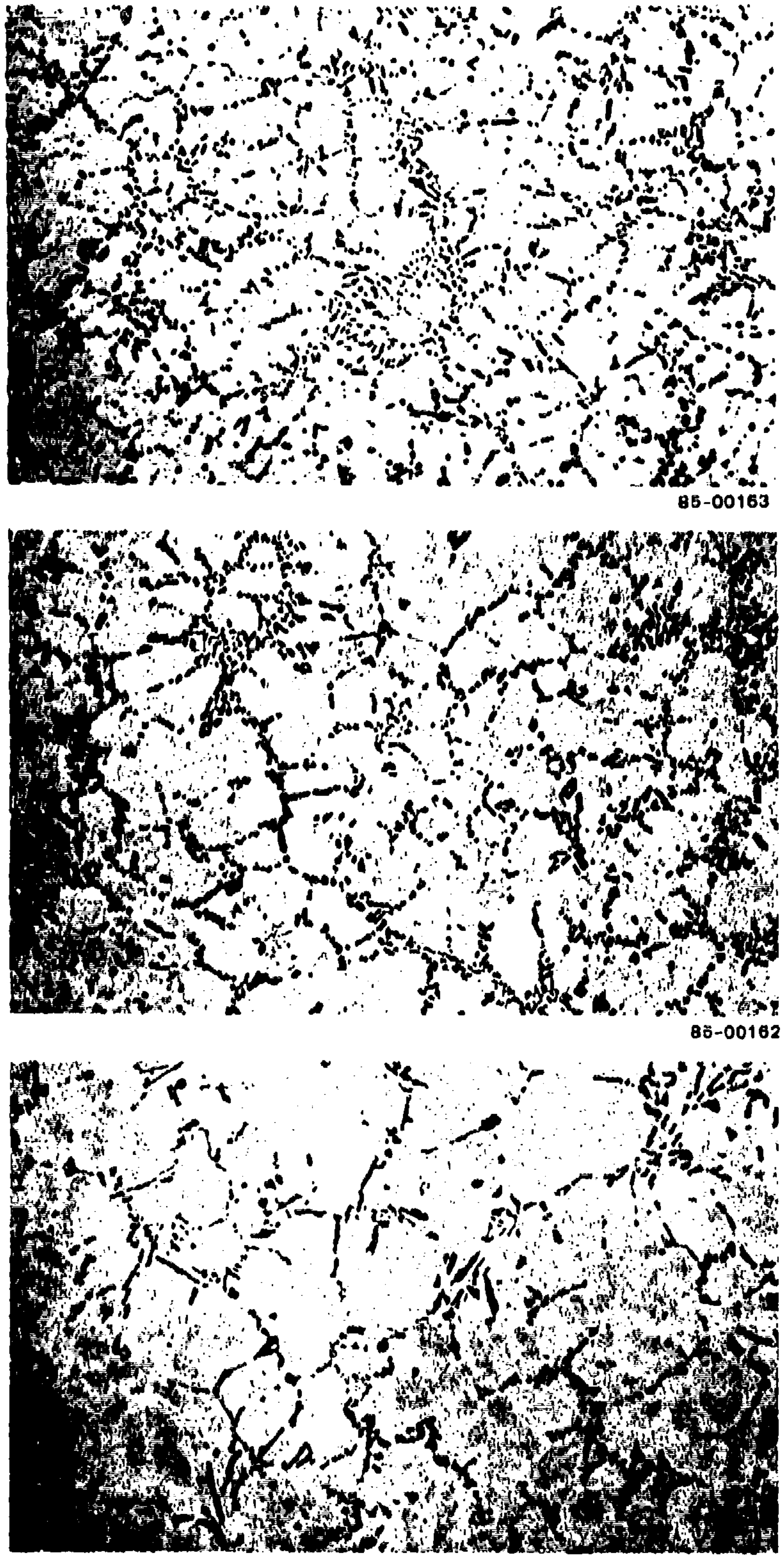


FIGURE 23. EFFECT OF DENDRITE ARM SPACING ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A357-T6



DAS 0.0014 INCH
TENSILE 52-45-4
MOLD CONTAINED COPE
AND DRAG CHILLS

85-00163

DAS 0.0019 INCH
TENSILE 48-43-1
NO CHILL IN COPE,
HALF THE WEIGHT OF
STANDARD CHILL IN DRAG

85-00162

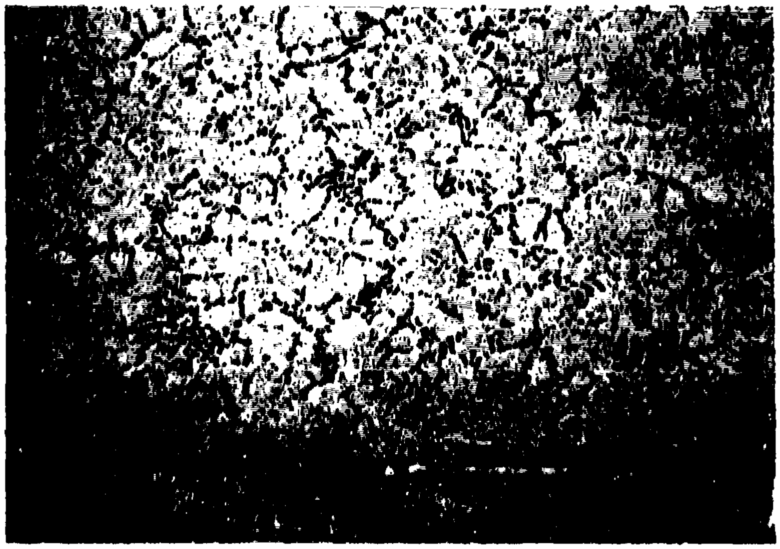
DAS 0.0035 INCH
TENSILE 45-42-1
NO CHILLS USED

ALL X100, KELLER ETCH

85-00161

FIGURE 24. EFFECT OF CHILLS ON THE MICROSTRUCTURE OF SAND CAST A357-T6

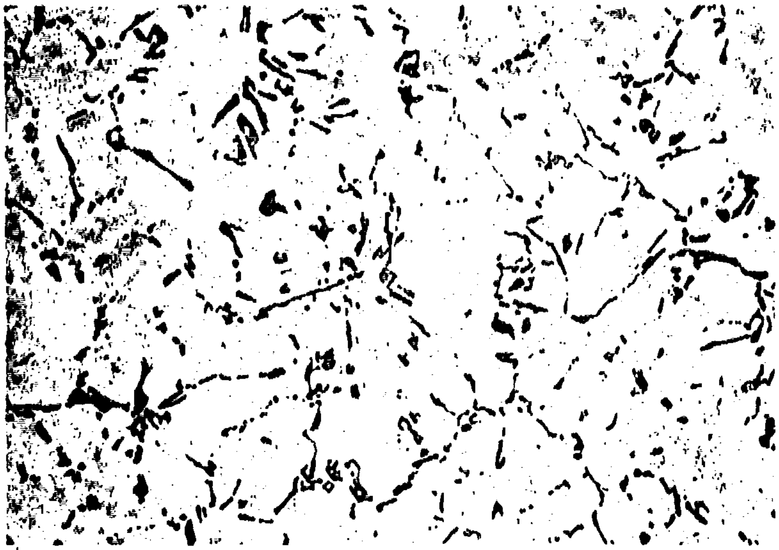
DAS 0.0013 INCH
TENSILE 50-41-5
MOLD TEMPERATURE, AMBIENT



85-00237-17, 18A

DAS 0.0027 INCH
TENSILE 45-43-2
MOLD TEMPERATURE 800°F

BOTH X100, KELLER ETCH



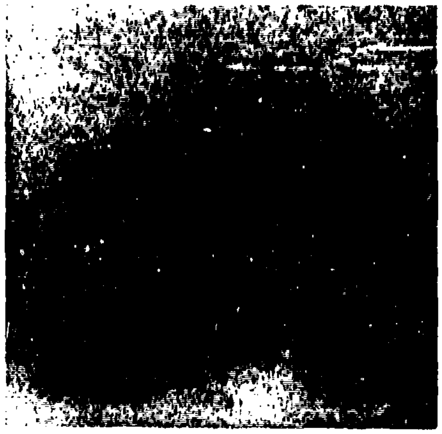
85-00237-17, 18B

FIGURE 25. EFFECT OF MOLD TEMPERATURE ON THE MICROSTRUCTURE OF SHELL INVESTMENT CAST A357-T6

GAS POROSITY (ELONGATED)
ATSM E 155 SEVERITY LEVEL
1.22 -1, 1/4 INCH

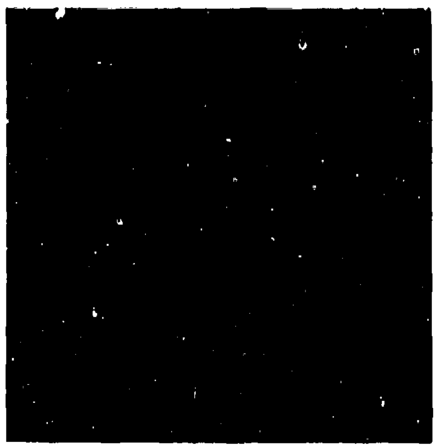
85-00239-13A

SHRINKAGE POROSITY OR SPONGE
ASTM E 155 SEVERITY LEVEL
2.2-1, 1/4 INCH



85-00239-13B

FOREIGN MATERIAL (LESS DENSE
MATERIAL) ASTM E 155 SEVERITY
LEVEL 3.11-1, 1/4 INCH (DROSS)



85-00239-13C

FIGURE 26. GRADE B RADIOGRAPHIC SEVERITY LEVEL PER MIL-C-6021

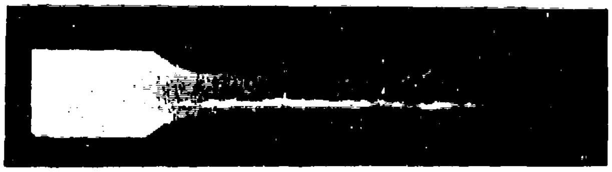
ALLOY A356-T6.
GAS POROSITY, ELONGATED
GRADE C

85-00239-19A

ALLOY A357-T6.
FOREIGN MATERIAL, LESS
DENSE, GRADE C (DROSS)

85-00239-19B

ALLOY A201.
SPONGE SHRINKAGE,
GRADE C



85-00239-19C

THESE PHOTOGRAPHS WERE REPRODUCED FROM THE RADIOGRAPHIC FILM, ACTUAL SIZE

FIGURE 27. RADIOGRAPHIC DEFECTS IN TENSILE TEST BARS, SHELL INVESTMENT CASTINGS

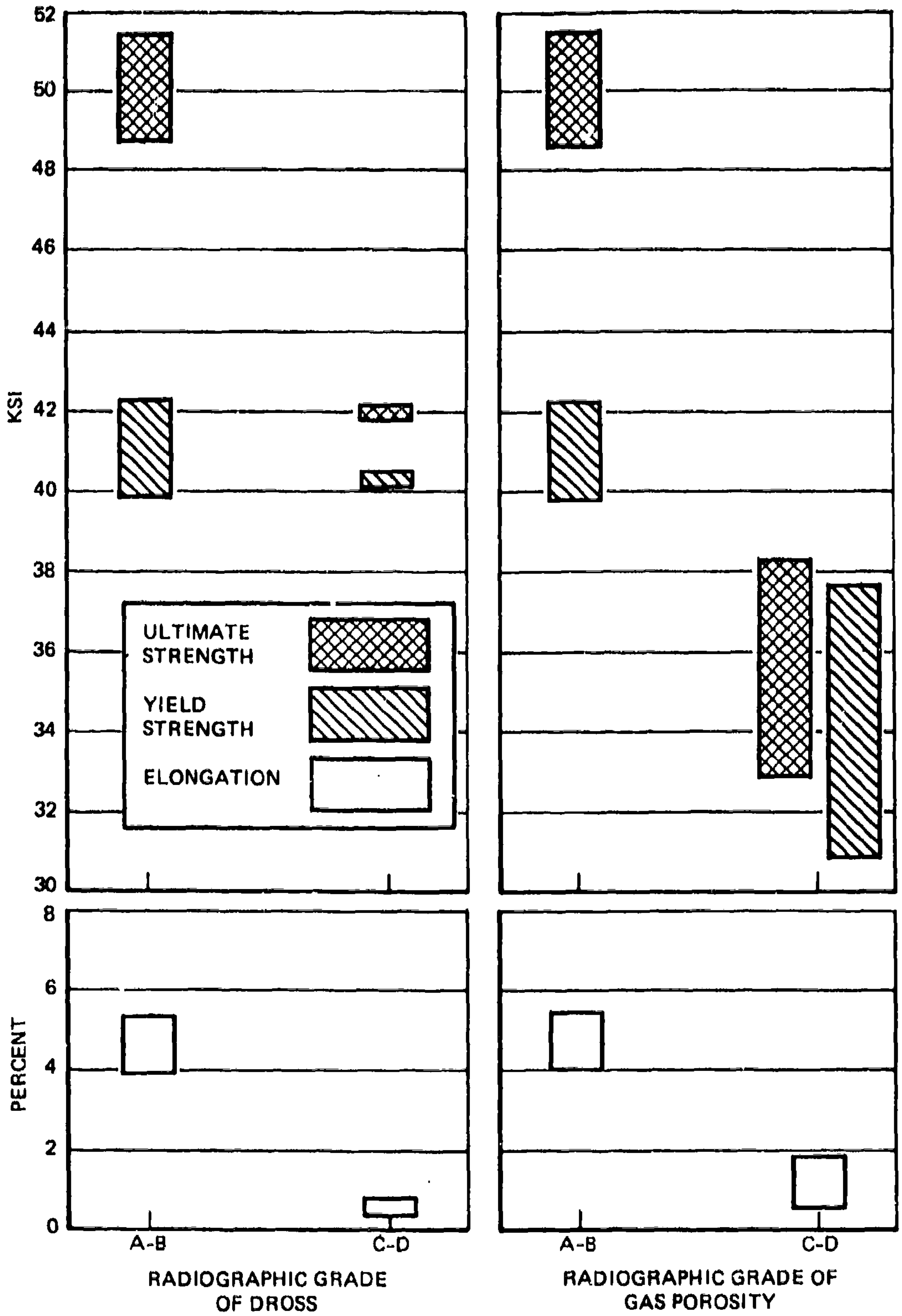


FIGURE 28. EFFECT OF DROSS AND GAS POROSITY ON THE TENSILE PROPERTIES OF SHELL INVESTMENT CAST A357-T6

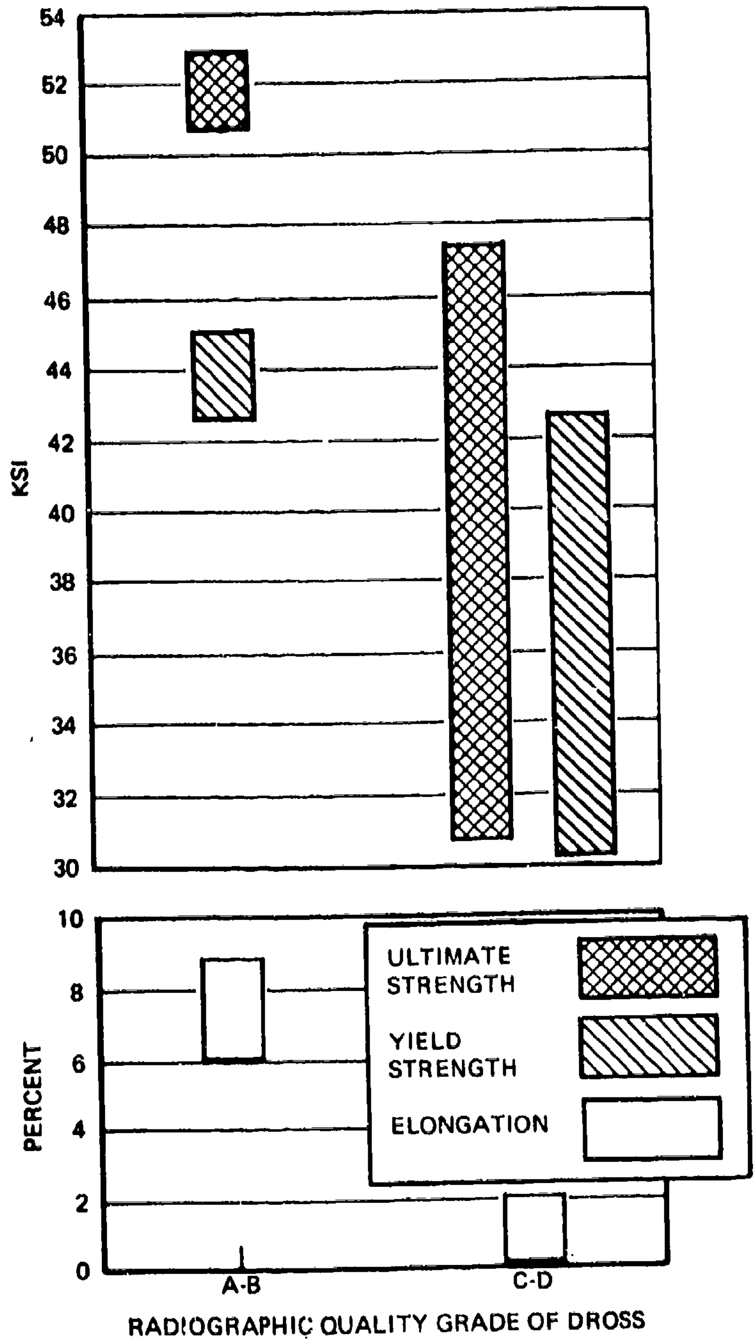


FIGURE 29. EFFECT OF DROSS ON THE TENSILE PROPERTIES OF SAND COMPOSITE CAST A357-T6

ductility decreased accordingly. The yield strength was not significantly affected.

2. ALLOY A356 SAND COMPOSITE AND SHELL INVESTMENT PLATES

a. Composition

Iron and magnesium contents of the melt were varied so their effect on the tensile properties of alloy A356 in the T6 heat treated condition could be determined. Magnesium is important because it acts as a strengthener; the precipitate of Mg_2Si hardens the alloy during artificial aging to the T6 condition. Iron embrittles the alloy due to the formation of an intermetallic compound of $FeSiAl_5$ which is insoluble and appears as a needle-like compound in the microstructure. The variations in melt composition were as follows:

MIL-A-21180 Specification Requirement (%)	Target Values (%)	Melt Composition (%)	
		Sand Composite	Shell Investment
0.20/0.40	0.20	0.20	0.22
Magnesium	0.30	0.27	Not obtained
	0.35	0.33	0.32
	0.40	0.40	0.39
0.20 Iron	0.05	0.08	0.06
Maximum	0.10	0.13	0.10
	0.15	Not obtained	0.12
	0.20	0.18	0.16

(1) Magnesium

The results (Figures 30 and 31) indicated a very significant increase in tensile strength and corresponding decrease in ductility when amounts of magnesium were increased. The results were identical for material cast by the sand composite and shell investment molding methods. Higher elongation values were evident in the sand composite molded cast plates.

(2) Iron

The effects of variations in amounts of iron (Figures 32, 33 and 34) indicated no significant effect on tensile strength, although ductility was reduced significantly in the shell investment molded plates. Ductility of the sand composite plates was not significantly reduced probably due to the smaller size of the iron compound in the sand composite plates.

b. Heat Treatment

To determine the significance of the heat treatment process variations, plates produced by the sand composite and shell investment methods were evaluated. They were heat treated with independent variations of the following:

1. Solution time
2. Quench water temperature
3. Delay time at room temperature
4. Artificial aging time.

The effects of each of the variables on the tensile properties of the plates were plotted on a graph to reveal trends.

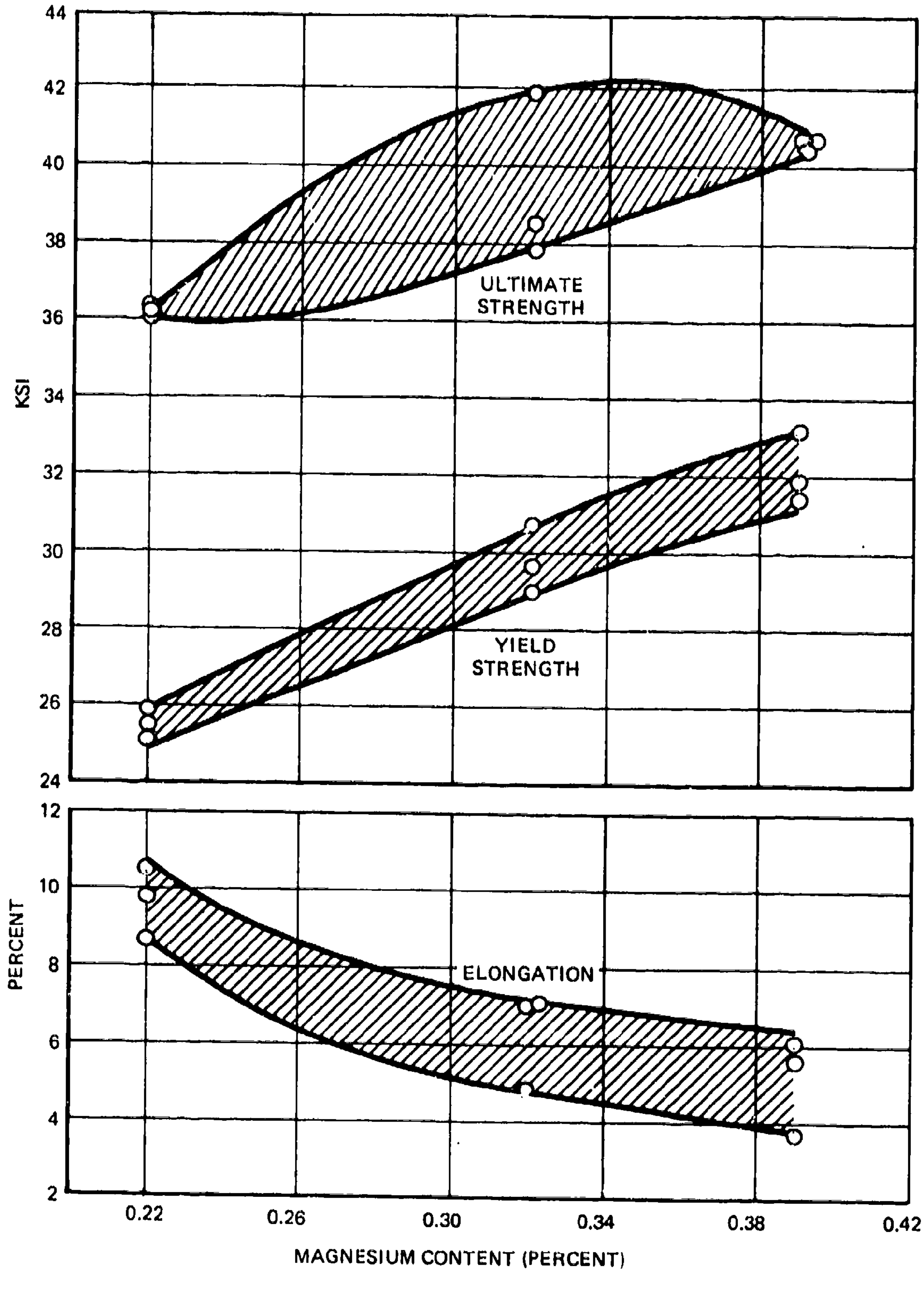


FIGURE 30. EFFECT OF MAGNESIUM CONTENT ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A356-T6

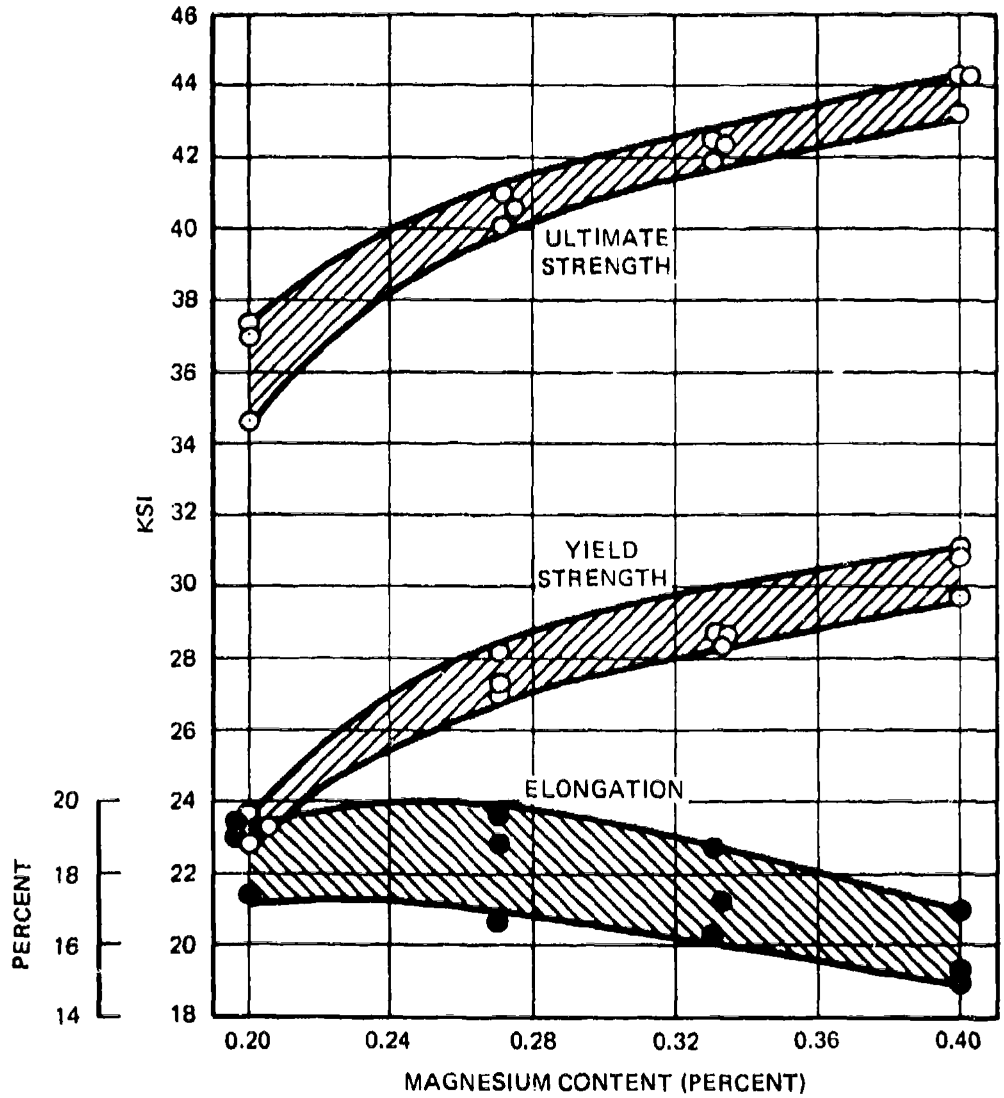


FIGURE 31. EFFECT OF MAGNESIUM CONTENT ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A356-T6

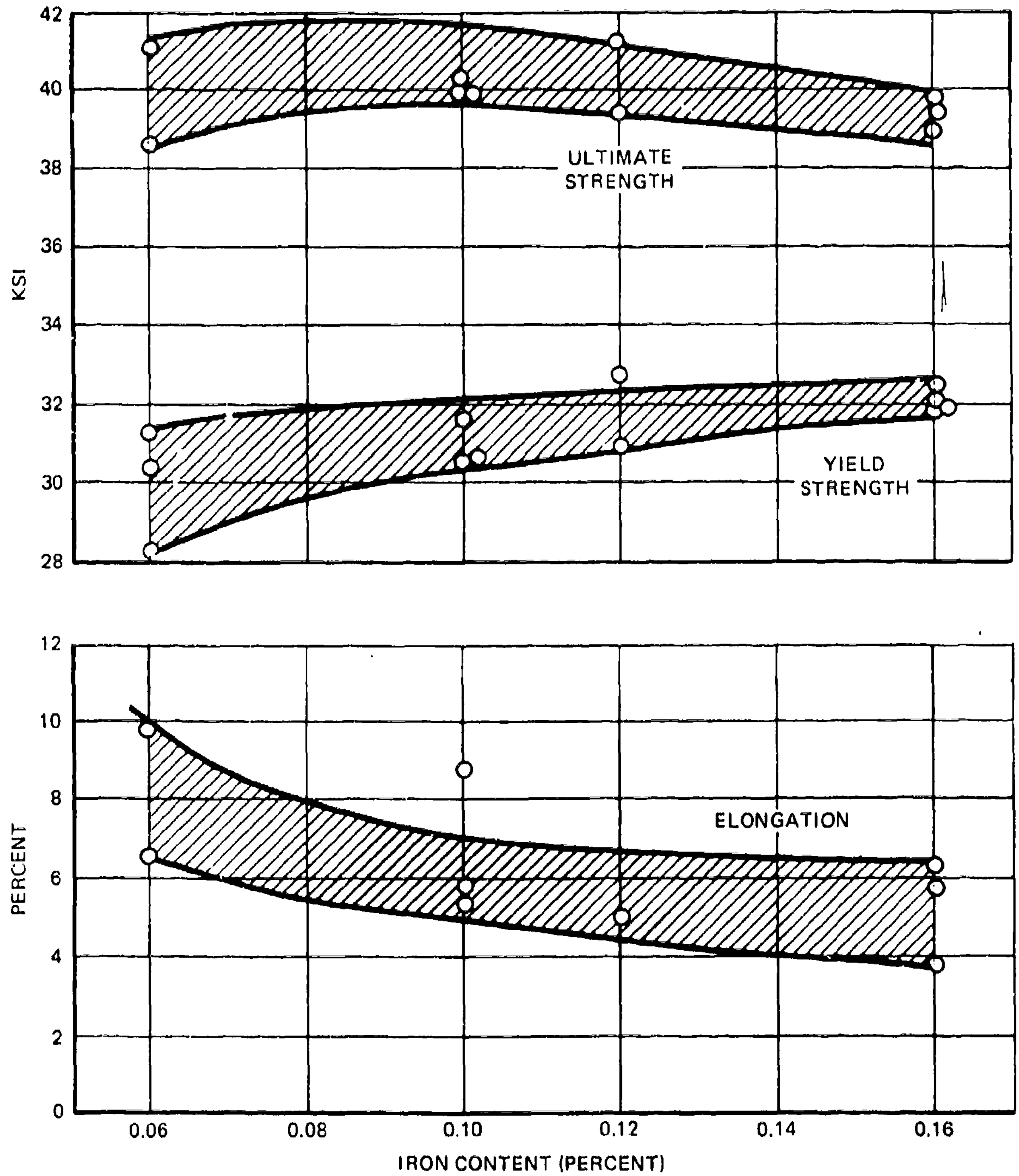


FIGURE 32. EFFECT OF IRON CONTENT ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A356-T6

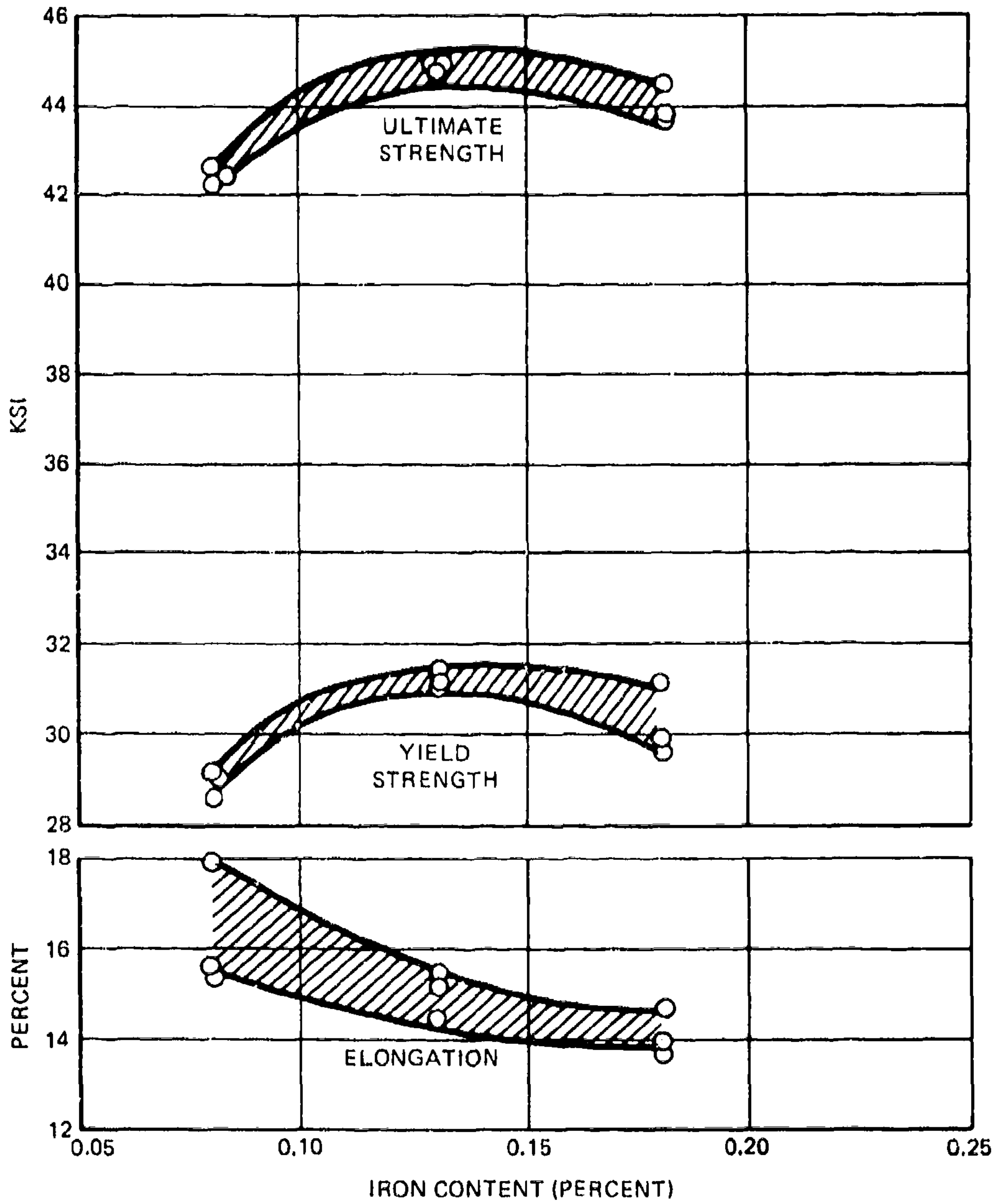
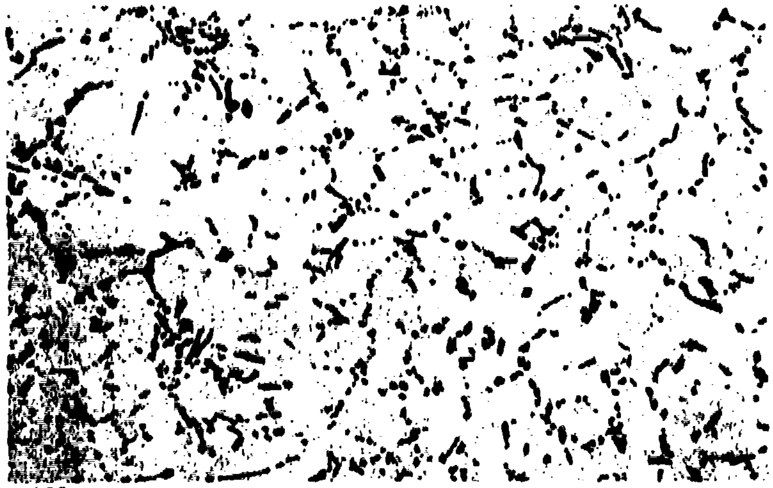


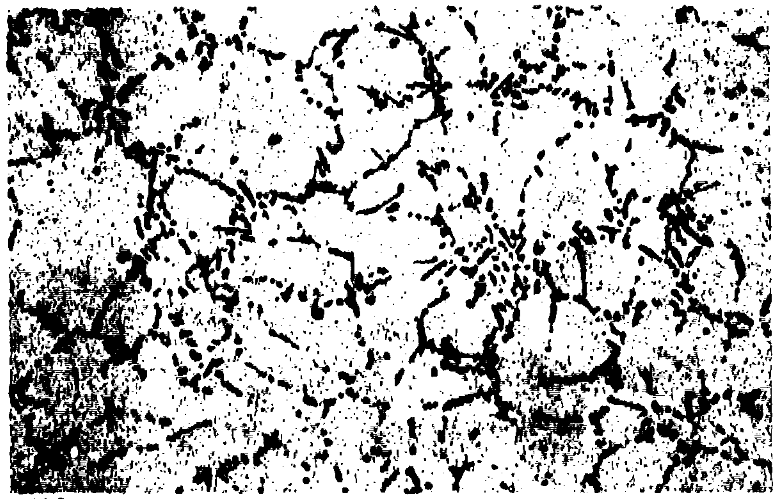
FIGURE 33. EFFECT OF IRON CONTENT ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A356-T6

DAS 0.0021 INCH
TENSILE 41-29-10
IRON 0.06 PERCENT



X100 85-00237-2A

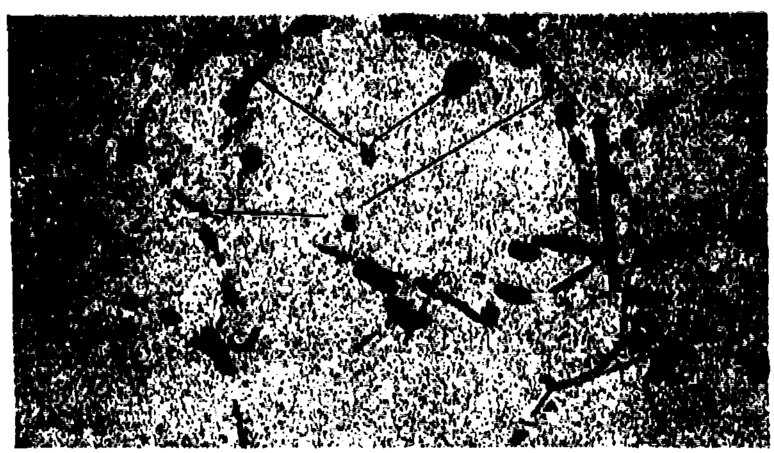
DAS 0.0021 INCH
TENSILE 39-32-4
IRON 0.20 PERCENT



X100 85-00237-2B

a = IRON COMPOUND
b = SILICON

ALL KELLER ETCH



X400 85-00160

FIGURE 34. EFFECT OF IRON CONTENT OF A356-T6 SHELL INVESTMENT CAST STRUCTURE

The following heat treatment processes were defined as standard for plates produced by each molding procedure:

Process Variable	Sand Composite Process	Shell Investment Process
Solution temperature	1000F	1000F
Solution time	18 hours	18 hours
Quenchant	Water at 40F	25% glycol-water at room temperature
Delay at room temperature	12 to 24 hours	12 to 24 hours
Artificial aging	310F, 8 hours	310F, 5 hours

(1) Solution Treatment Time

The solution times investigated were periods of six, twelve, and eighteen hours with the sand composite and four, eight and eighteen hours with the shell investment castings at 1000F (Figures 35 and 36). Increased solution times only produced a minor beneficial effect on the ultimate strength and ductility of sand composite molded (3/4-inch thick) and shell investment molded (1/10-inch thick) plates. Increasing the solution period resulted in a spheroidizing effect on the silicon particles (Figure 37).

(2) Quench Water Temperature

The effect of quench water temperatures of 40, 100, 160, and 212F was evaluated. Quench water temperature was found to have had very little effect on the 1/10-inch thick shell investment molded plates (Figure 38). All tensile properties on sand composite plates were decreased by increasing water temperature (Figure 39). The differences, of the sand composite molded and shell investment molded plates, were presumed to be related to the plate thickness. Improvement in tensile properties of 3/4-inch thick plates occurred with the use of colder quench water. No significant improvement in ductility was found.

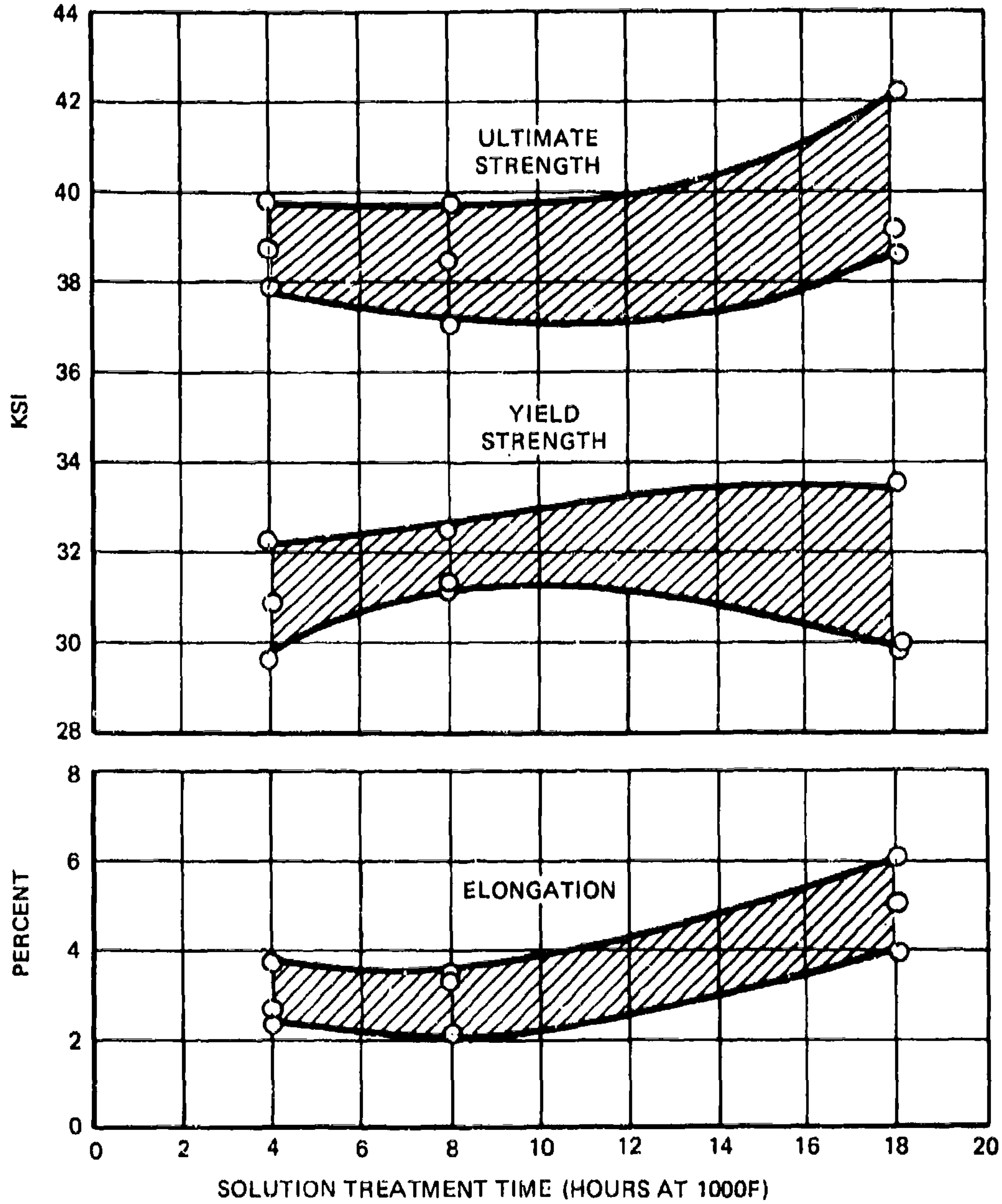


FIGURE 35. EFFECT OF SOLUTION HEAT TREATMENT TIME ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A356-T6

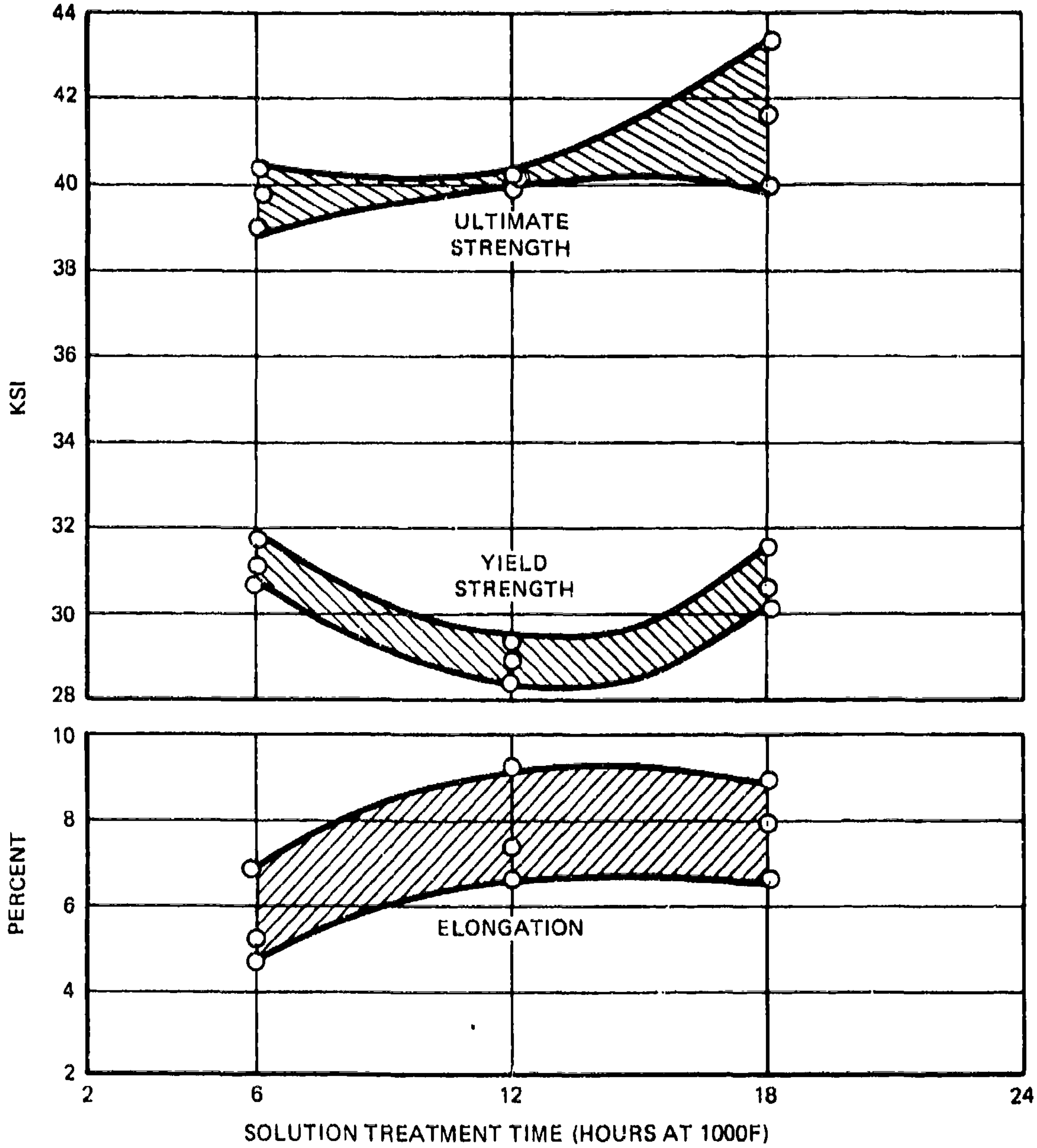


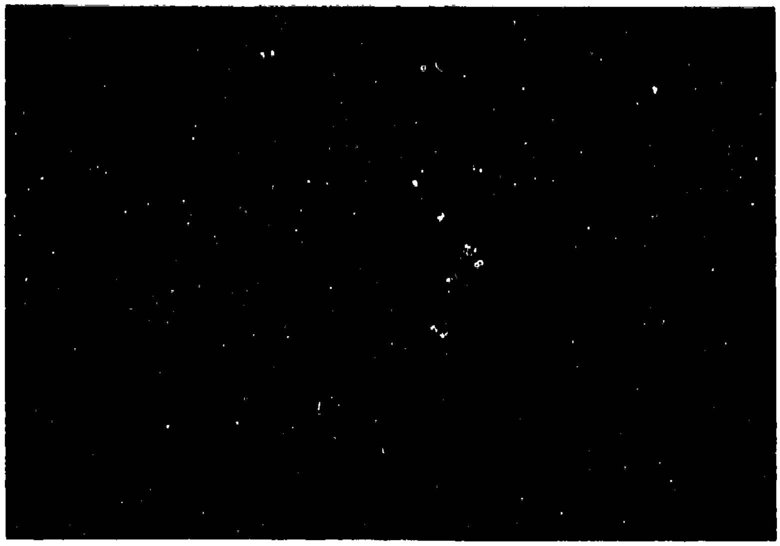
FIGURE 36. EFFECT OF SOLUTION HEAT TREATMENT TIME ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A356-T6

DAS 0.0018 INCH
TENSILE 38-30-3
SOLUTION TIME, 4 HOURS

85-00237-19, 20A

DAS 0.0019 INCH
TENSILE 39-30-6
SOLUTION TIME, 18 HOURS.
SILICON PARTICLES LESS
SPIKY, MORE
SPHEROIDIZED

BOTH X100, KELLER ETCH



85-00237-19, 20B

FIGURE 37. EFFECT OF SOLUTION TREATMENT TIME ON THE CAST STRUCTURE OF SHELL INVESTMENT A356-T6

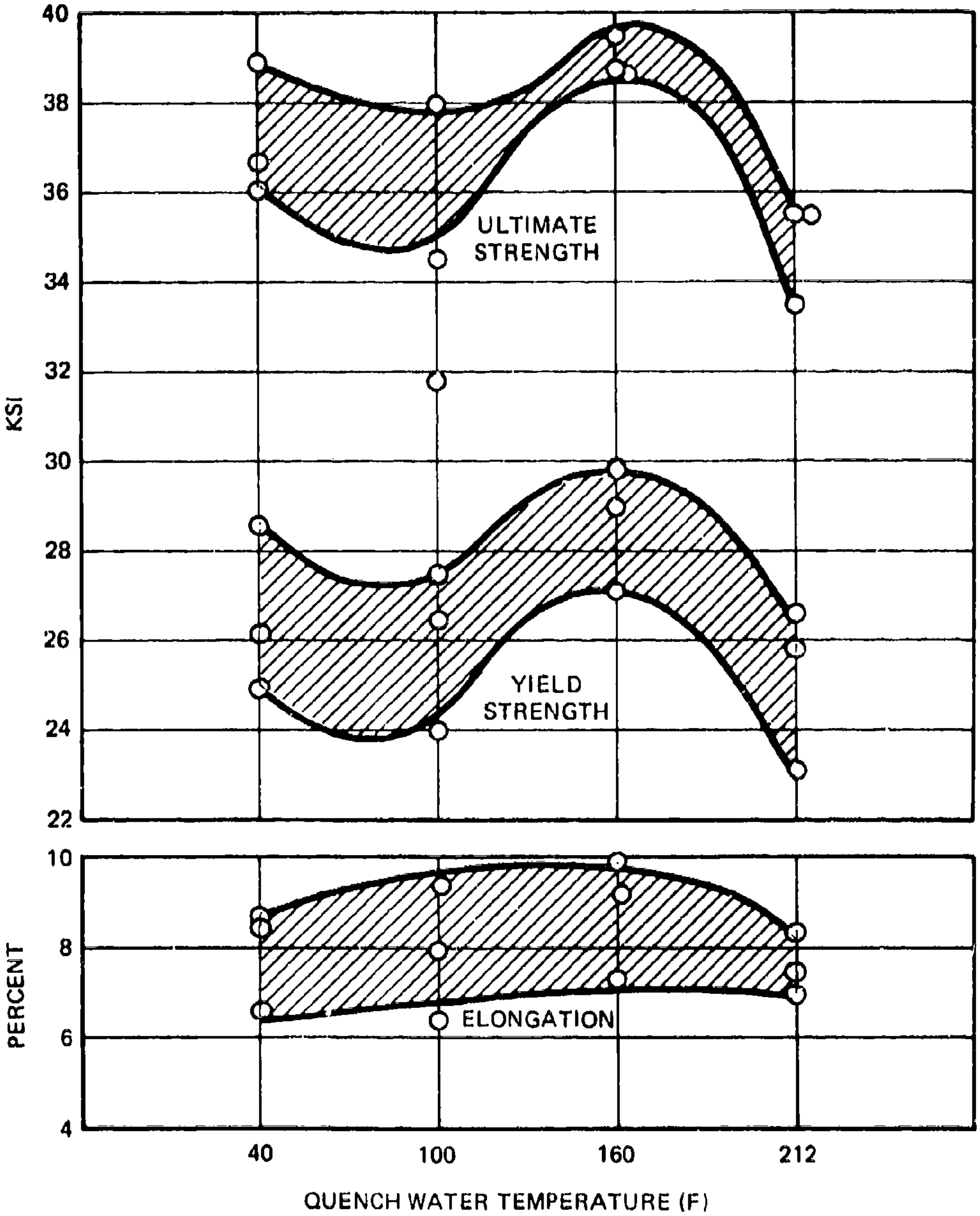


FIGURE 38. EFFECT OF QUENCH WATER TEMPERATURE ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A356-T6

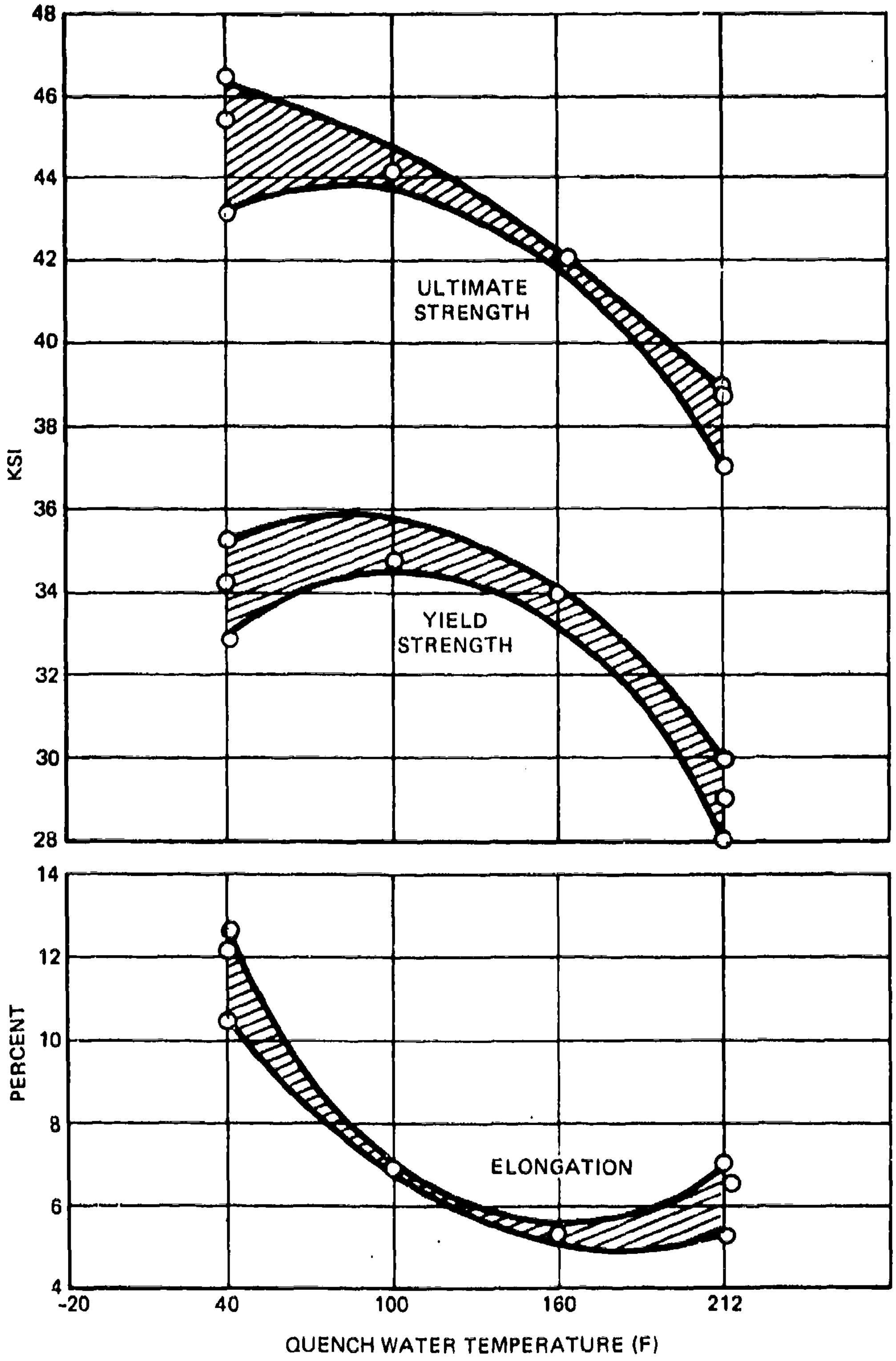


FIGURE 39. EFFECT OF QUENCH WATER TEMPERATURE ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A356-T6

(3) Delay Period at Room Temperature

The effect of aging delay was investigated for periods of zero, one-half, one, and three days between the quench and the start of artificial aging (Figures 40 and 41). The tensile properties of shell investment molded plates were not significantly affected by the aging delay period. However, after a delay period of one-half day, the yield strength of the sand composite molded plates showed a significant decrease, while the ductility increased significantly. The change in yield strength and ductility during the first day of age delay can not be explained and needs further investigation. Ductility improvements, after a 24-hour room temperature delay period following the quench, have been reported for T6 material (Reference 11).

(4) Artificial Aging Time

The effect of artificial aging time at 310F was investigated. Sand composite plates were aged for zero, four, six, eight, and ten hours, while shell investment plates were aged for six, eight, ten, twelve, and fourteen hours. The results (Figures 42 and 43) clearly indicated the importance of aging time. As the aging time increased, the strength increased, while ductility was reduced. These trends are well known for precipitation hardening alloy such as A356.

c. Solidification Rate

Variations of DAS resulted from changes in the solidification rate. The DAS of the sand composite plate was changed with the extent of chill material added to the mold (Figure 44). The DAS of the shell investment molded plates was changed by varying the mold temperature and plate thickness (Figures 45 and 46). The tensile properties decreased with an increase in DAS.

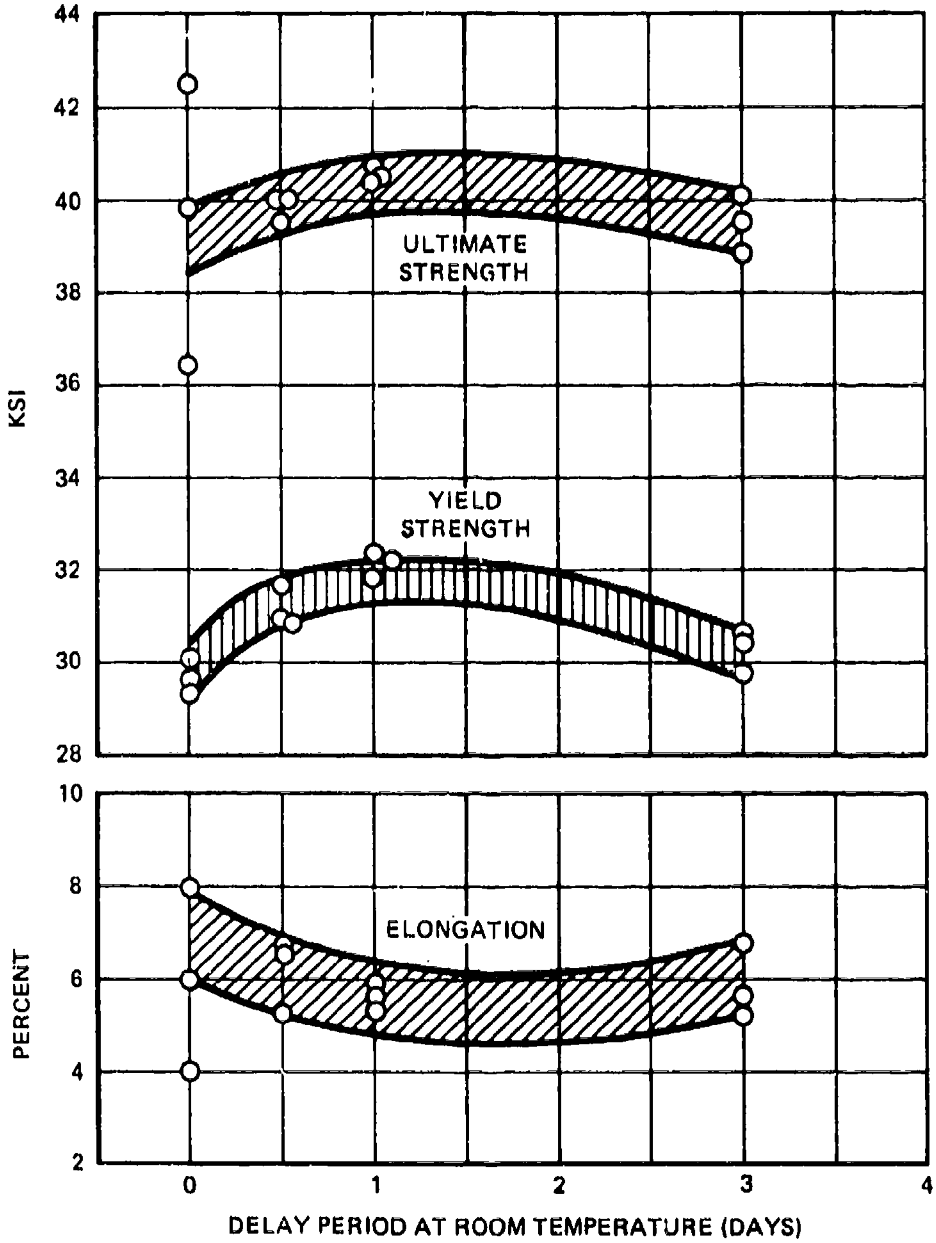


FIGURE 40. EFFECT OF DELAY PERIOD AT ROOM TEMPERATURE ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A356-T6

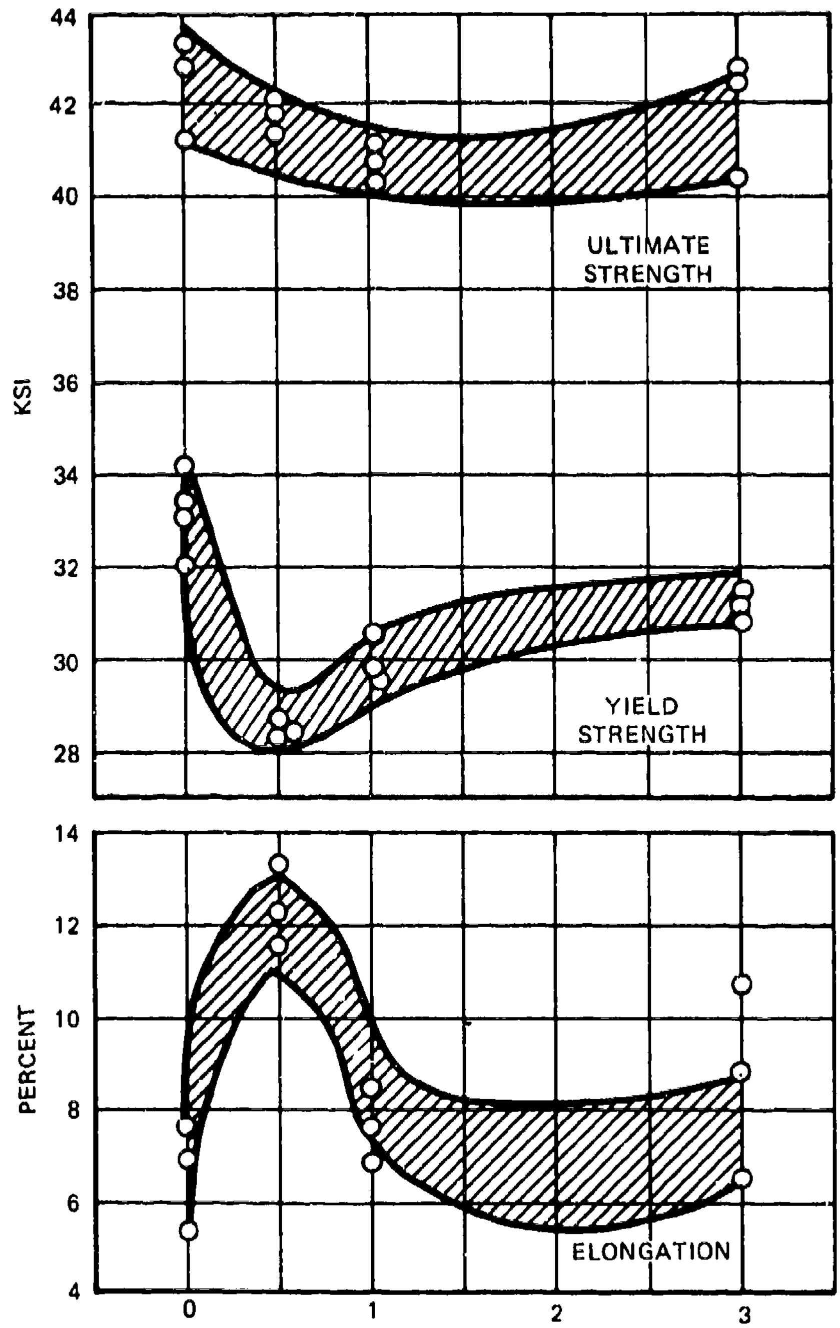


FIGURE 41. EFFECT OF DELAY PERIOD AT ROOM TEMPERATURE ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A356-T6

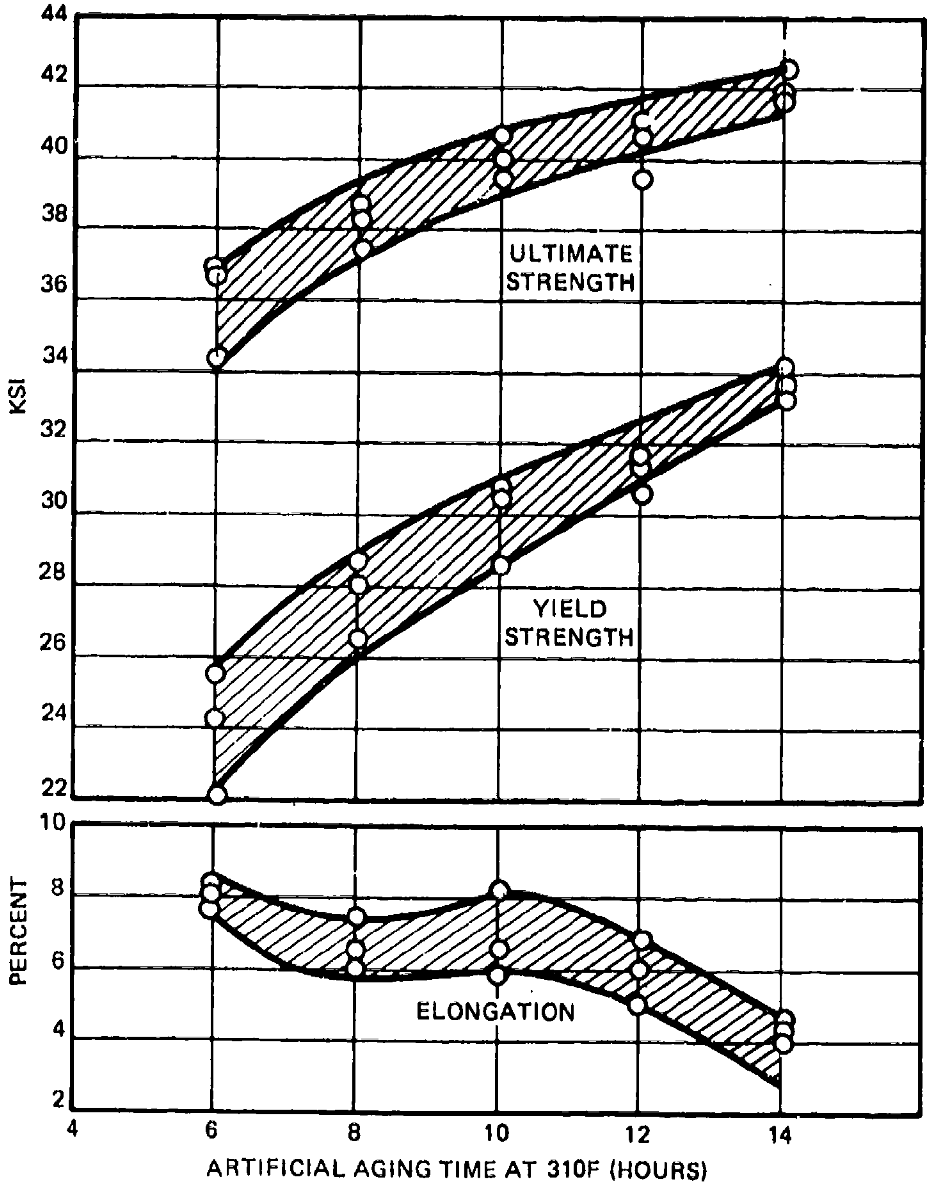


FIGURE 42. EFFECT OF ARTIFICIAL AGING TIME ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A356-T6

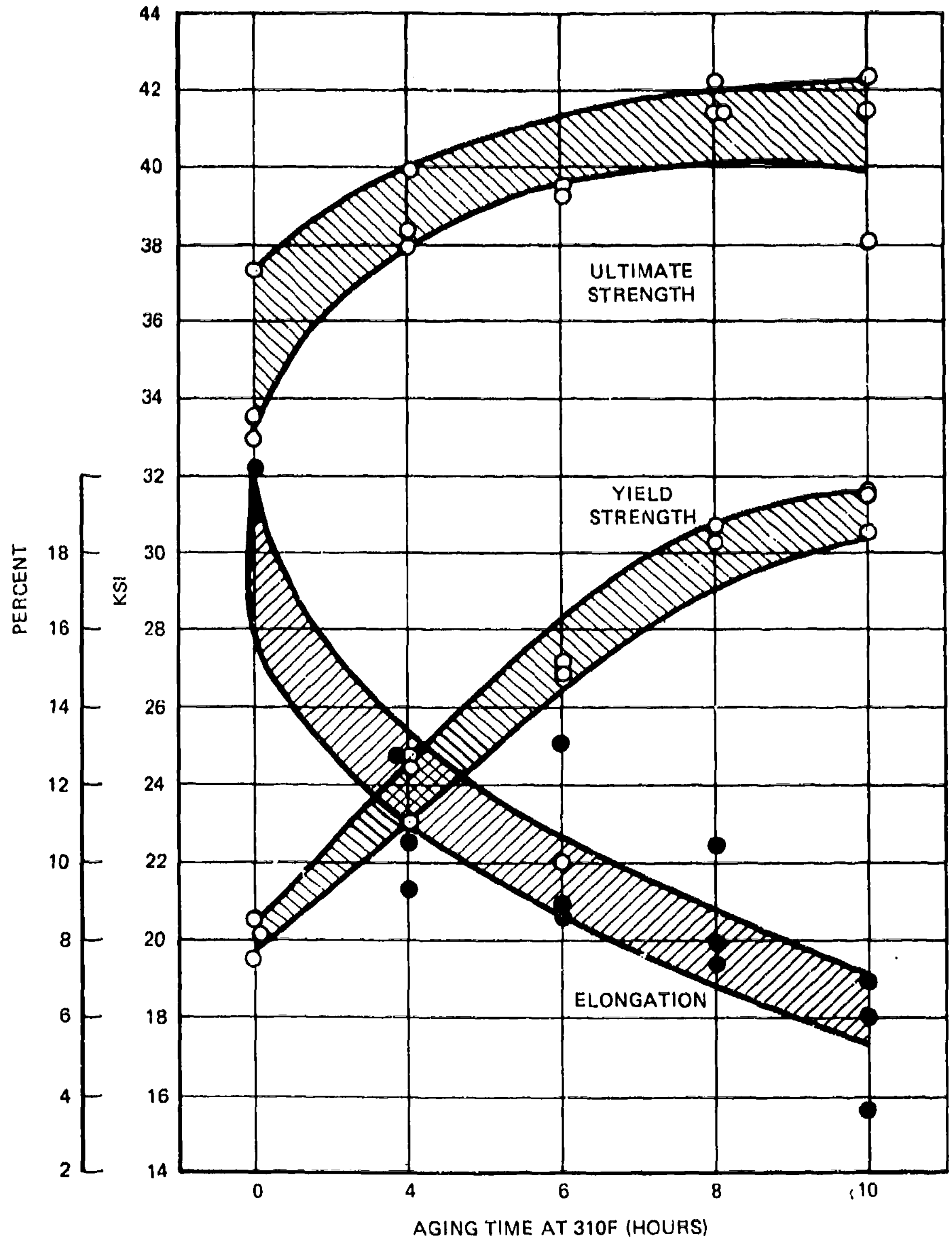
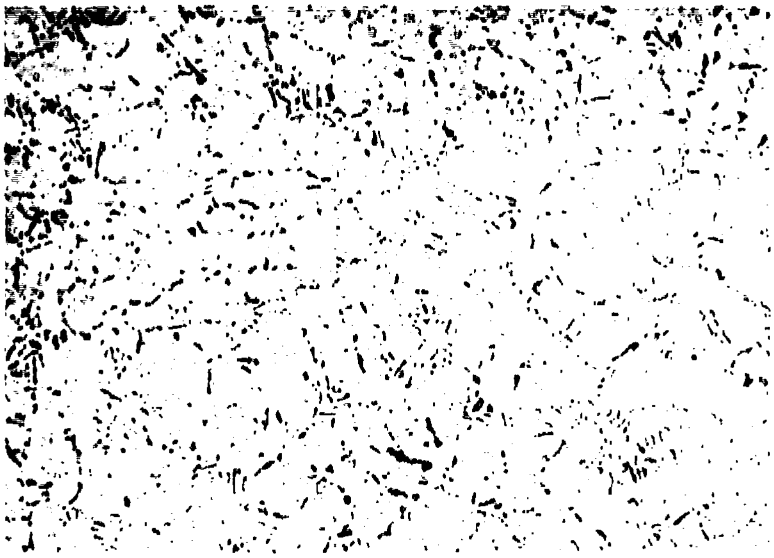


FIGURE 43. EFFECT OF ARTIFICIAL AGING TIME ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A356-T6

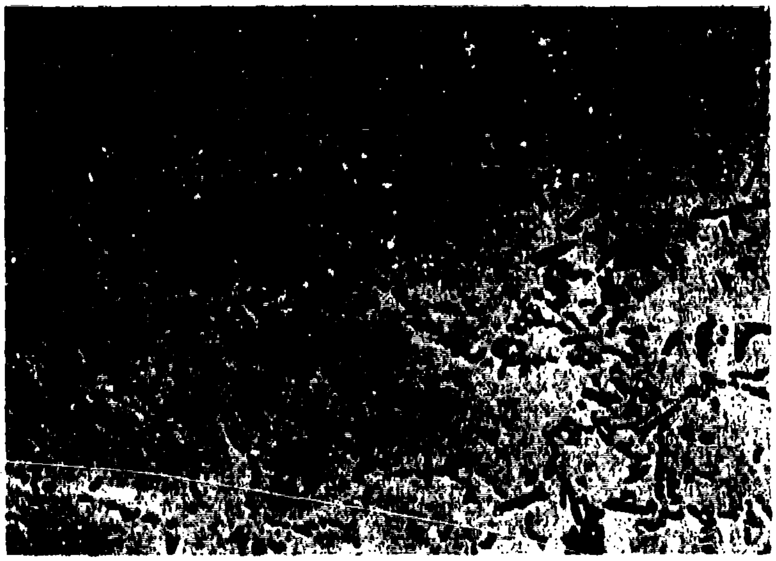
DAS 0.0015
TENSILE 45-34-7
MOLD CONTAINED COPE
AND DRAG CHILLS



85-00237-1A

DAS 0.0026
TENSILE 40-33-4
NO CHILLS USED

BOTH X100, KELLER ETCH



85-00237-1B

FIGURE 44. EFFECT OF METAL CHILLS ON THE MICROSTRUCTURE OF SAND CAST A356-T6

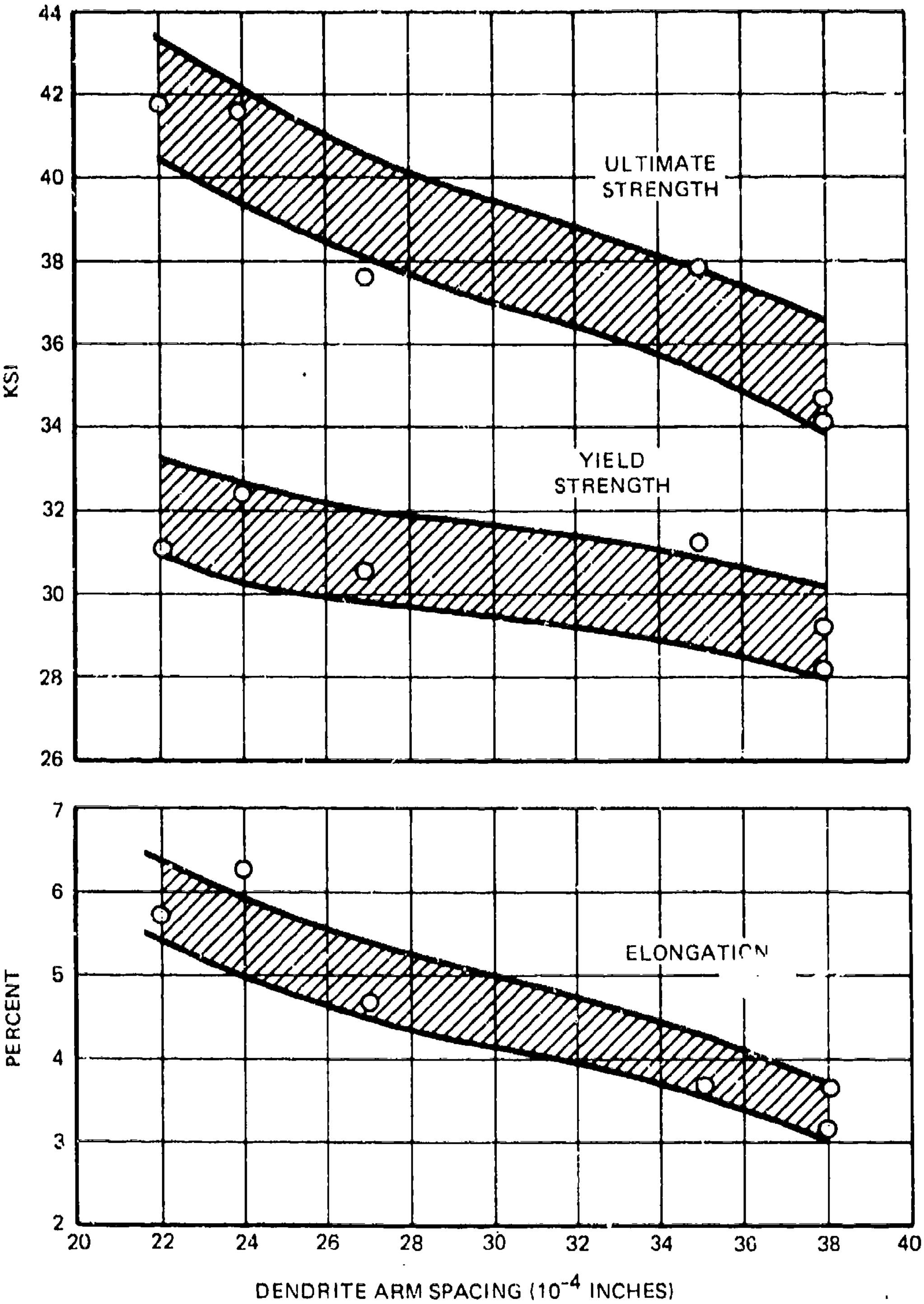


FIGURE 45. EFFECT OF DENDRITE ARM SPACING ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A356-T6

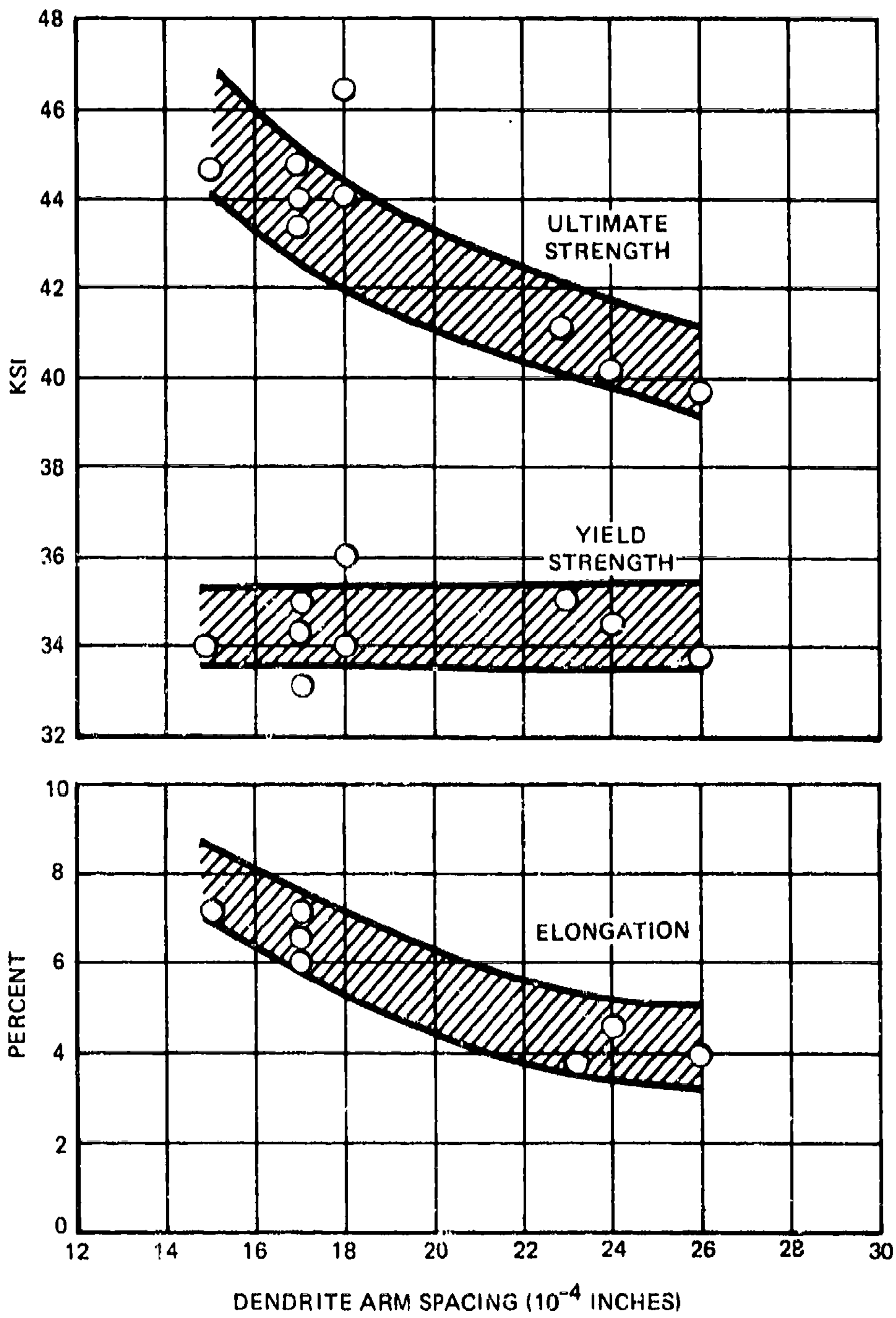


FIGURE 46. EFFECT OF DENDRITE ARM SPACING ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A356-T6

By varying the shell investment plate thicknesses, various solidification rates were produced that caused changes in the microstructure (Figure 47).

d. Radiographic Quality

Radiographic quality was varied in this investigation to represent two levels. The higher level of quality was equal to, or better than, a Grade B per MIL-C-6021. This represents the highest quality available for production castings and is usually required in high-stress areas of premium quality castings. The lower levels of qualities investigated were Grades C and D per MIL-C-6021. The types of radiographic defects evaluated were:

1. Dross (less dense material)
2. Shrinkage sponge
3. Porosity.

These defects are the most prevalent causes for rejection of MIL-A-21180 aircraft castings. All types of defects in each alloy were not produced in plates cast from each molding process. The tensile properties of specimens representing the two levels of radiographic quality are shown in Figures 48, 49, 50, and 51. In each instance, when the quality level changed from Grade B or better, to Grade C or D, the ultimate strength and ductility decreased significantly. The yield strength was not significantly affected.

3. ALLOY A201 SAND COMPOSITE AND SHELL INVESTMENT PLATES

a. Composition

The chemical elements of A201: copper, silver, and magnesium, contribute to its strength. These three elements form precipitates during aging to strengthen the alloy. Iron is an impurity that forms an insoluble compound that reduces the ductility of the alloy. Silicon is also an impurity, that

PLATE THICKNESS 0.13 INCH
DAS 0.003 INCH

PLATE THICKNESS 0.40 INCH
DAS 0.005 INCH

PLATE THICKNESS 1.10 INCH
DAS 0.008 INCH

ALL X100 KELLER ETCH

FIGURE 47. EFFECT OF PLATE THICKNESS ON THE MICROSTRUCTURE OF SHELL INVESTMENT CAST A356-T6

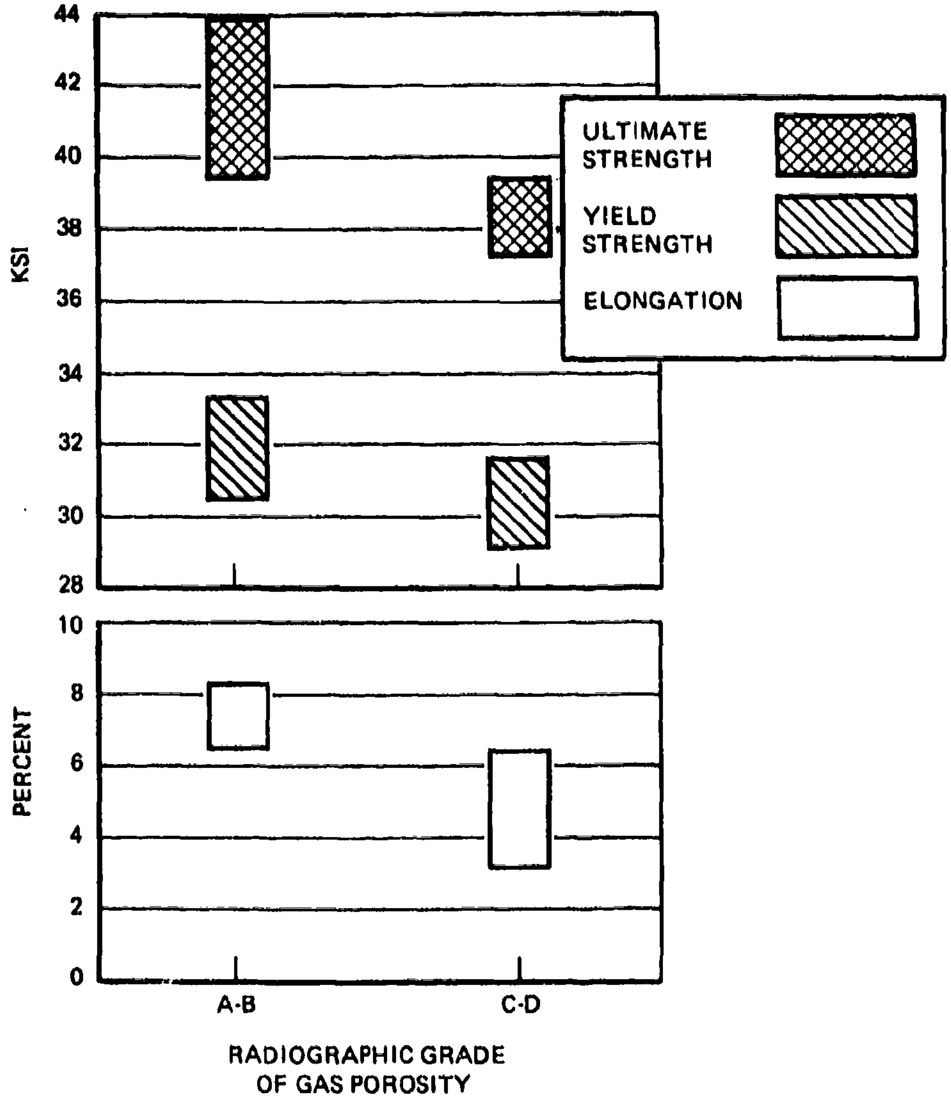


FIGURE 48. EFFECT OF GAS POROSITY ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A356-T6

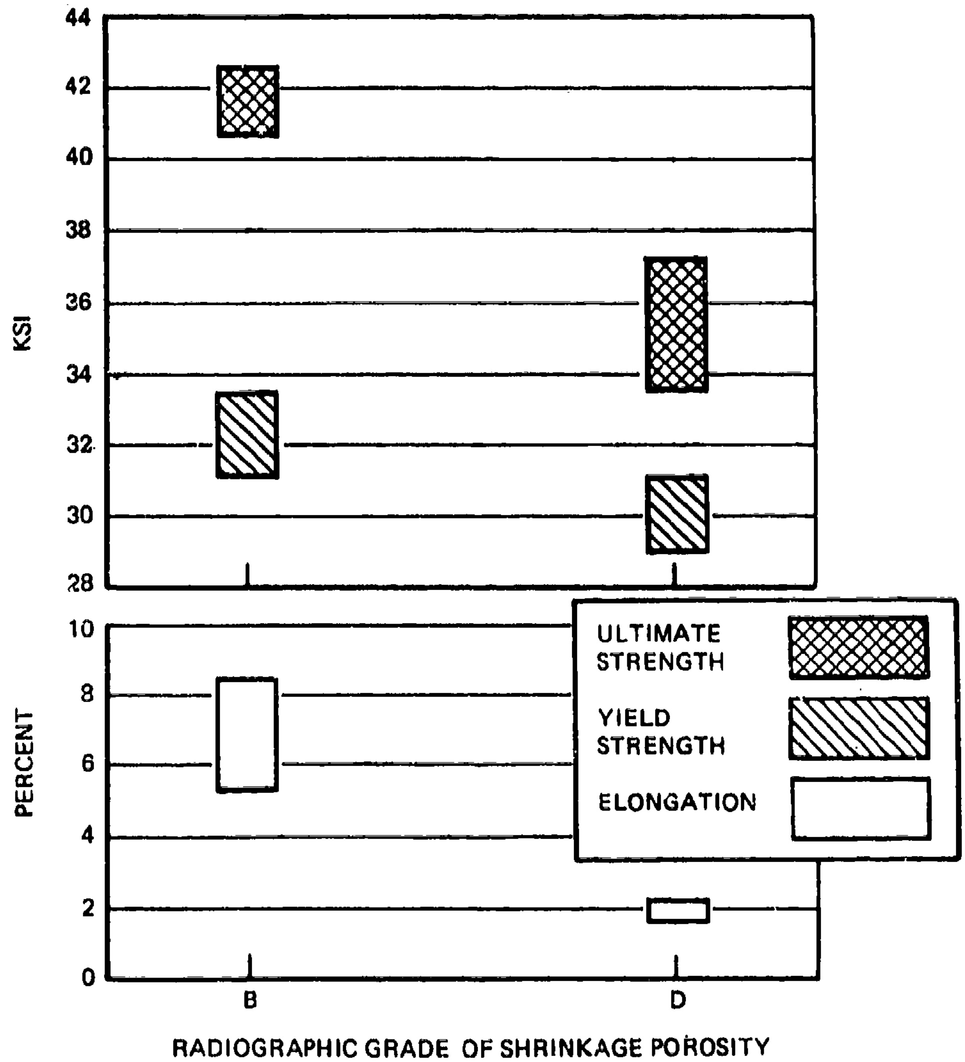


FIGURE 49. EFFECT OF SHRINKAGE POROSITY ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A356-T6

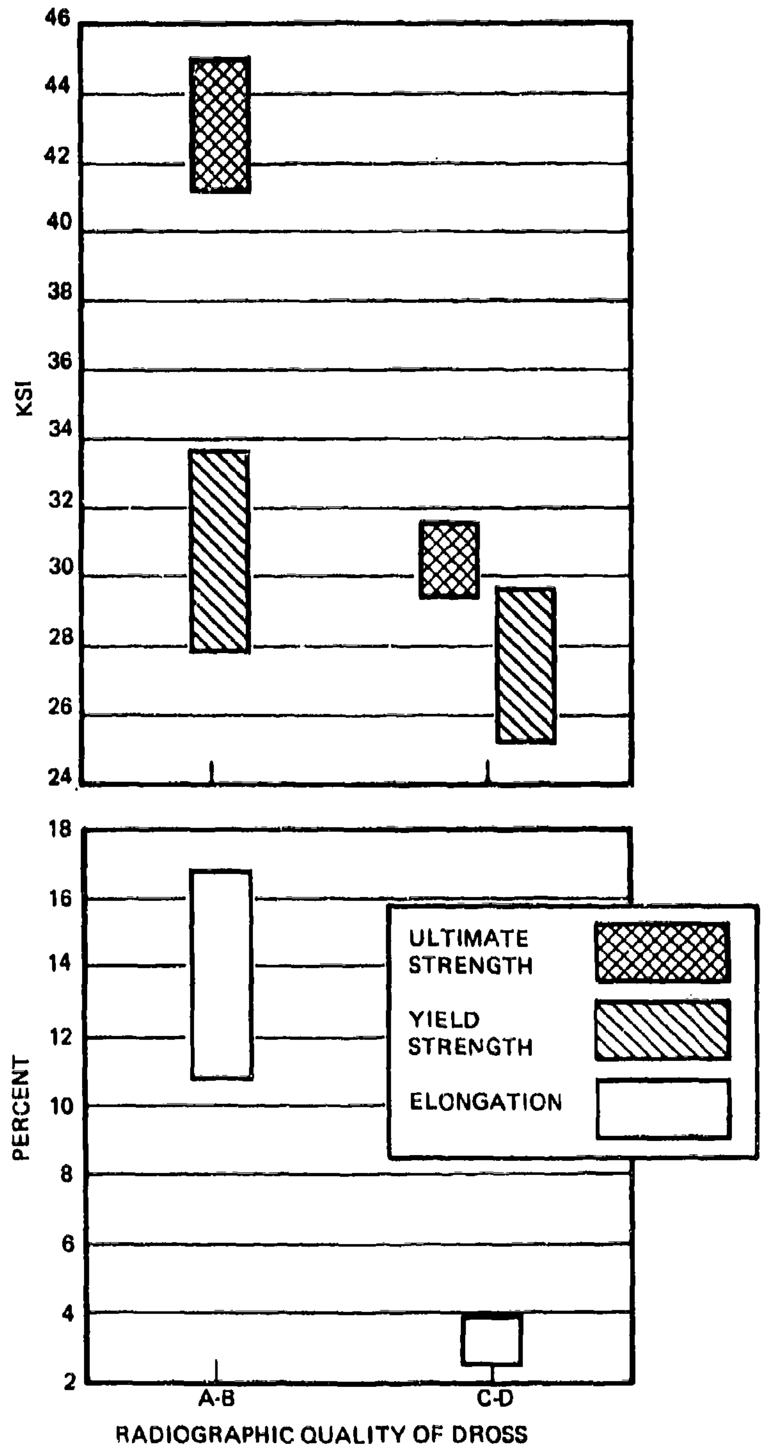


FIGURE 50. EFFECT OF DROSS ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A356-T6

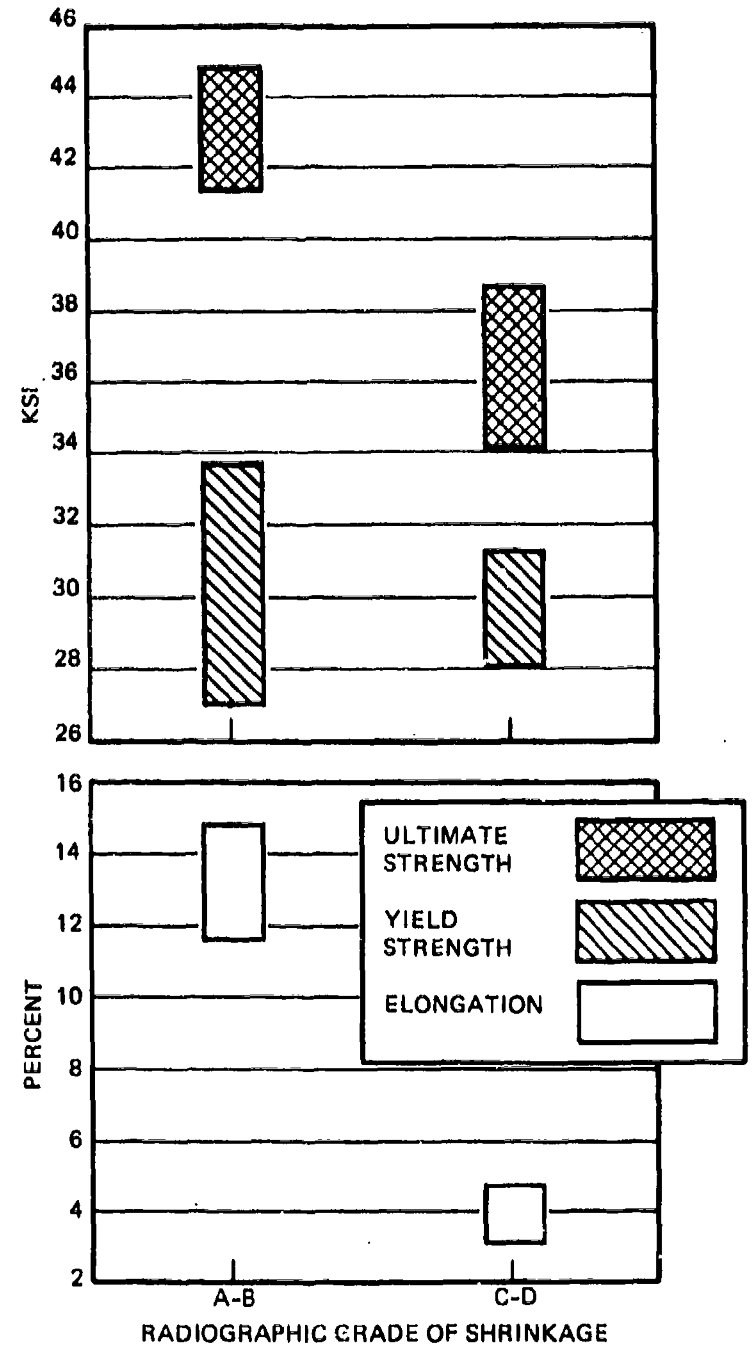


FIGURE 51. EFFECT ON RADIOGRAPHIC GRADE OF SHRINKAGE ON THE TENSILE PROPERTIES OF SAND COMPOSITE CAST A356-T6

possibly forms an eutectic compound which is vulnerable to incipient melting during heat treatment. The composition variations were:

MIL-A-21180 Specification Requirement (%)	Target Values %	Melt Composition (%) Sand Composite	Shell Investment
0.15-0.35	0.15	0.07	0.16
Magnesium	0.25	Not obtained	0.26
	0.30	0.29	0.29
	0.35	0.35	0.35
4.0-5.0	4.4	4.1	4.1
Copper	4.6	4.4	4.7
	4.8	4.5	4.8
	5.0	5.0	5.0
0.4-1.0	0.4	0.4	0.4
Silver	0.6	0.6	0.6
	0.8	0.8	0.8
	1.0	1.0	1.0
0.10	0.06	0.04	0.06
Maximum	0.10	0.10	0.09
Iron	0.15	0.16	0.15
	0.20	Not obtained	0.20
0.05	0.05	0.05	0.05
Maximum	0.10	0.09	0.09
Silicon	0.15	0.11	0.14
	0.20	Not obtained	0.20

(1) Magnesium

The affect of magnesium on the tensile properties of plates cast by both molding procedures was similar with the exception of the investment cast plates with 0.16% magnesium content. Increasing the magnesium content resulted in an increase of strength but a decrease of ductility as shown in Figures 52 and 53.

(2) Copper

Increased copper content resulted in significant increases in strength and ductility of sand composite molded plates (Figure 54). It was unusual that the ductility varied in the same manner as the strength properties. More evaluation is needed to clarify this effect. The tensile strength and ductility of shell investment molded plates varied only slightly with increasing copper contents (Figure 55).

(3) Silver

Silver had a very significant influence on the tensile properties. In general, higher contents increased the strength and decreased the ductility for both sand composite and shell investment molded plates (Figures 56 and 57). The ultimate and yield strengths of the sand composite molded plates reached a maximum at 0.6 percent and then remained constant with further increases of silver. The strength of the shell investment molded plates continued to increase after a slight inflection, between 0.4 and 0.6 percent silver. A content of 0.6 percent has previously been reported as nearly optimum for strength properties in the T6 heat treat condition (Reference 12).

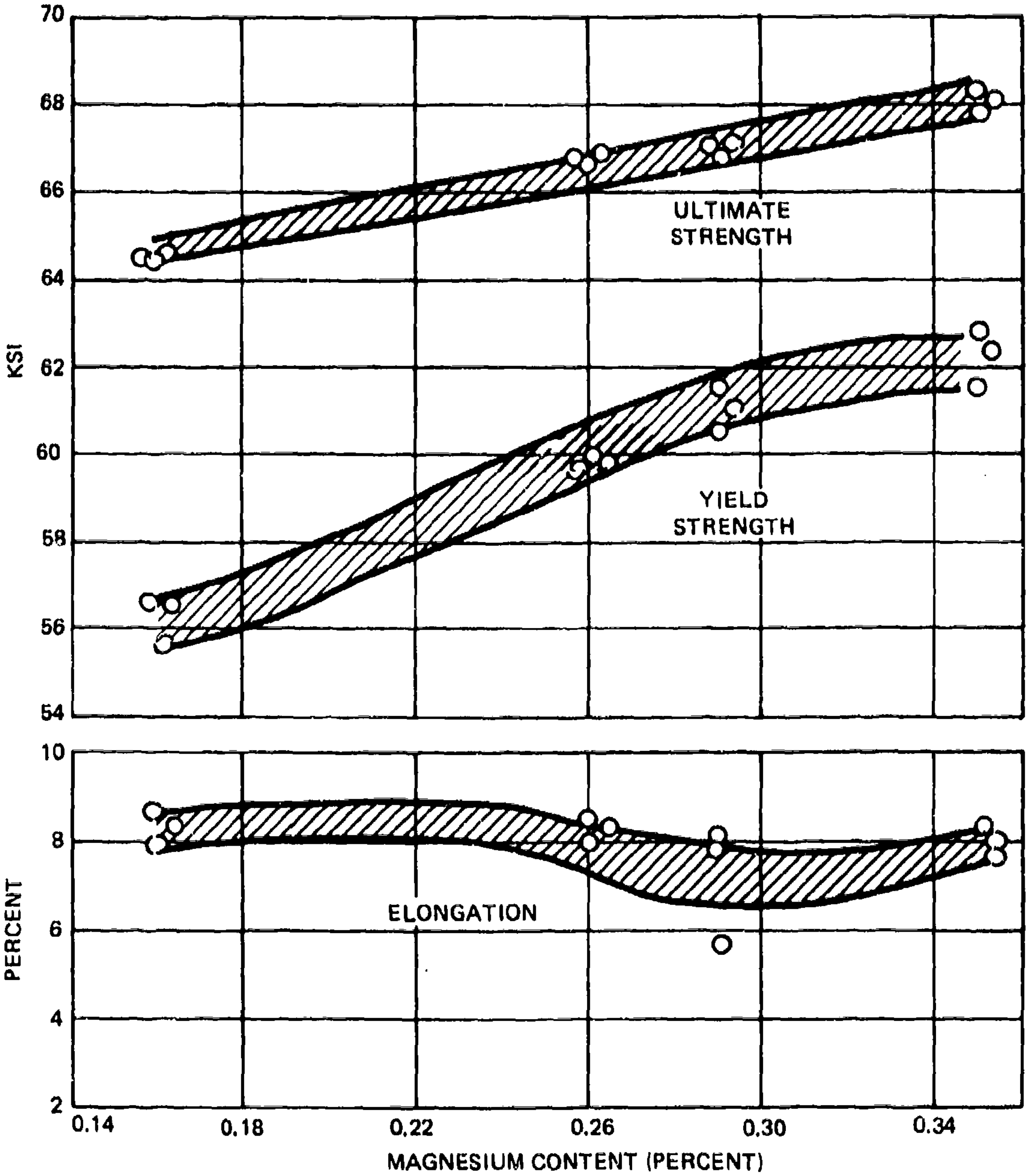


FIGURE 52. EFFECT OF MAGNESIUM CONTENT ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A201-T7

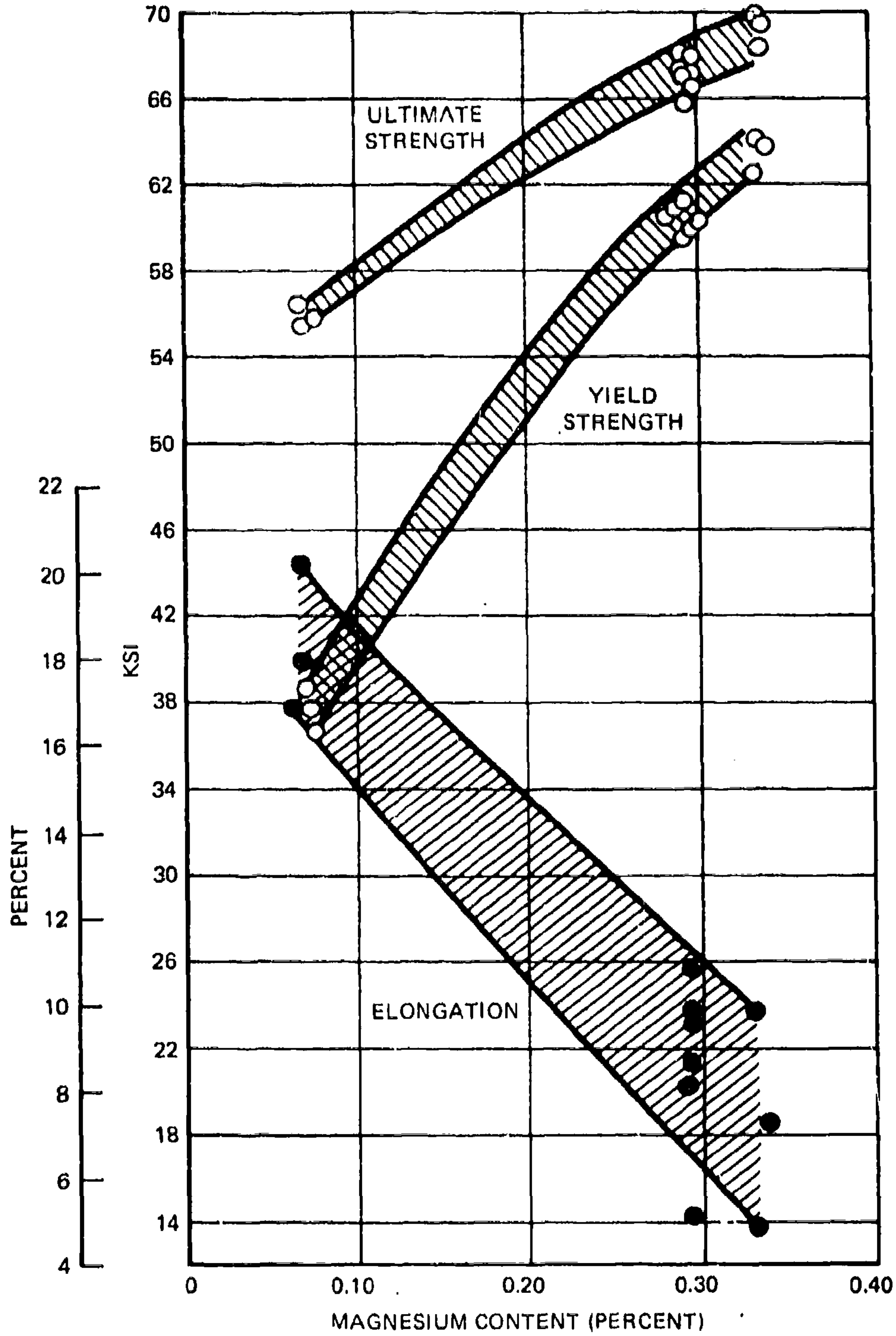


FIGURE 53. EFFECT OF MAGNESIUM CONTENT ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A201-T7

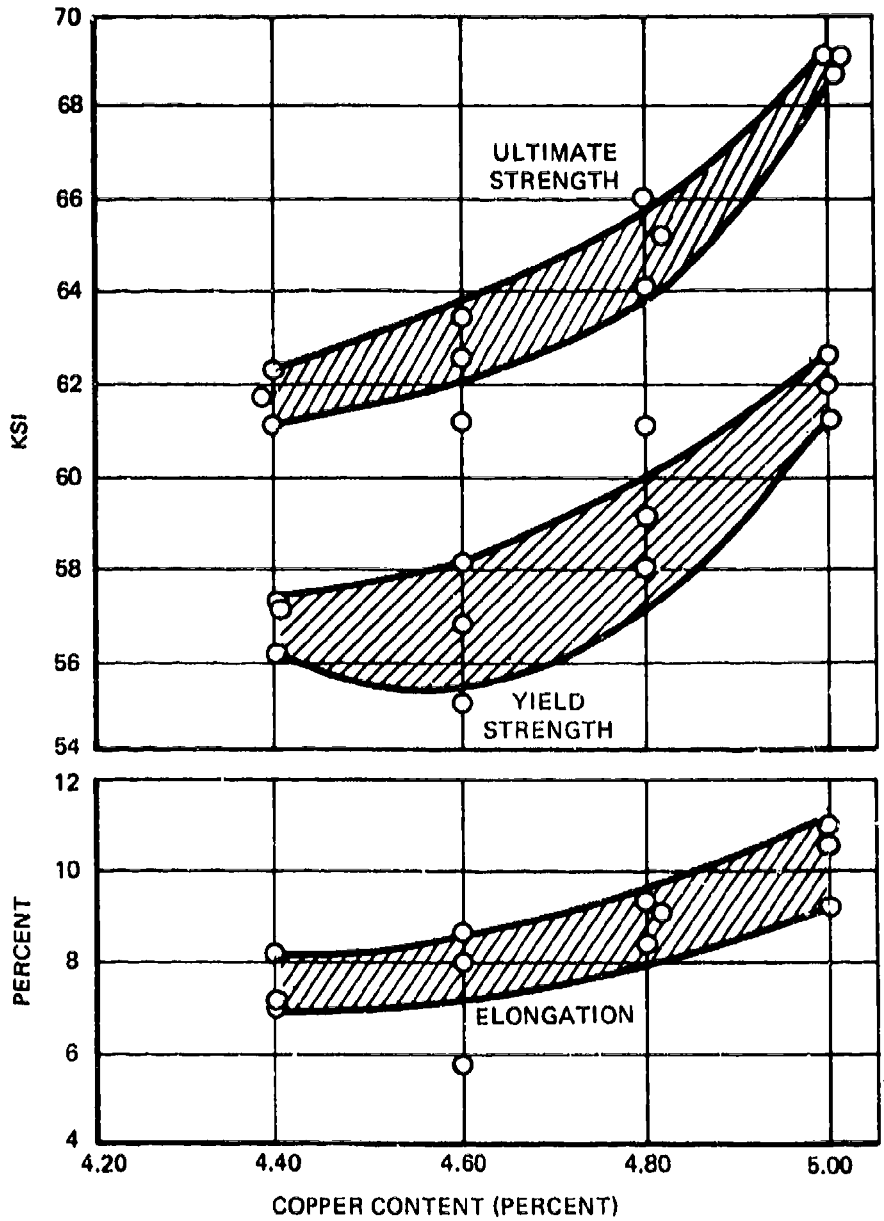


FIGURE 54. EFFECT OF COPPER CONTENT ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A201-T7

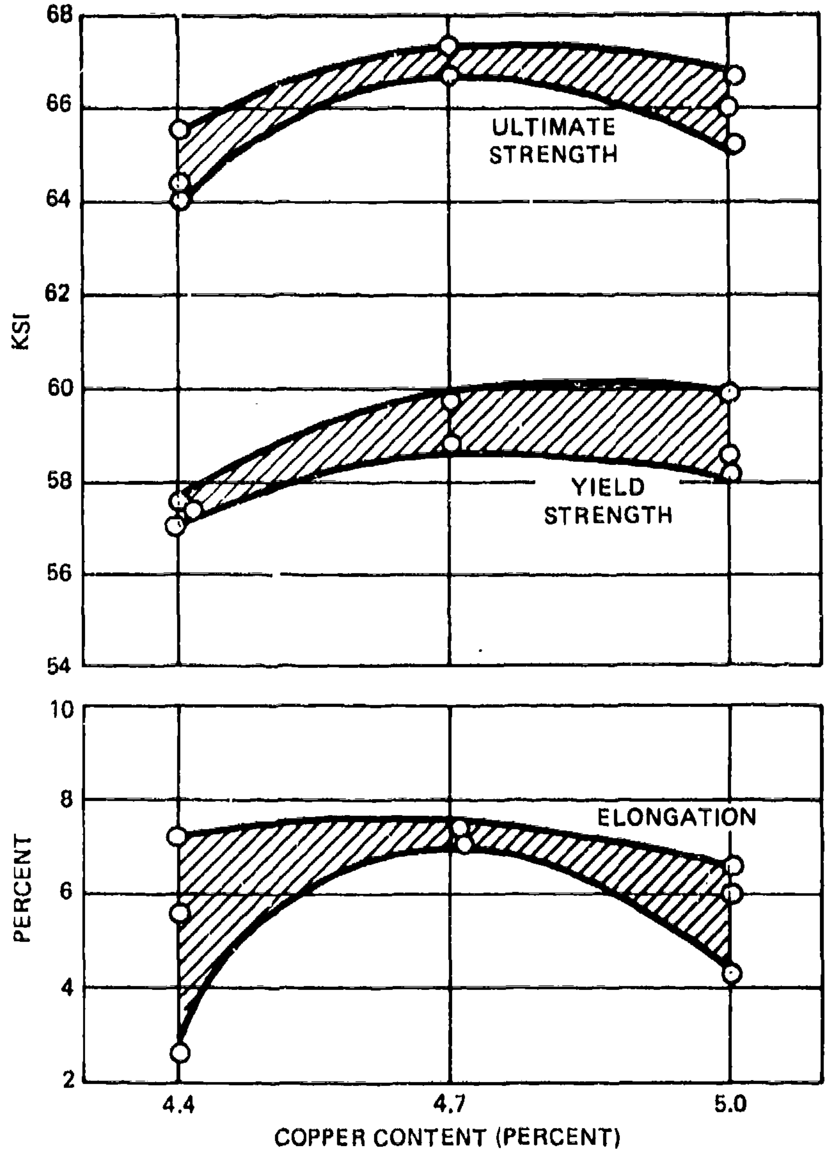


FIGURE 55. EFFECT OF COPPER CONTENT ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A201-T7

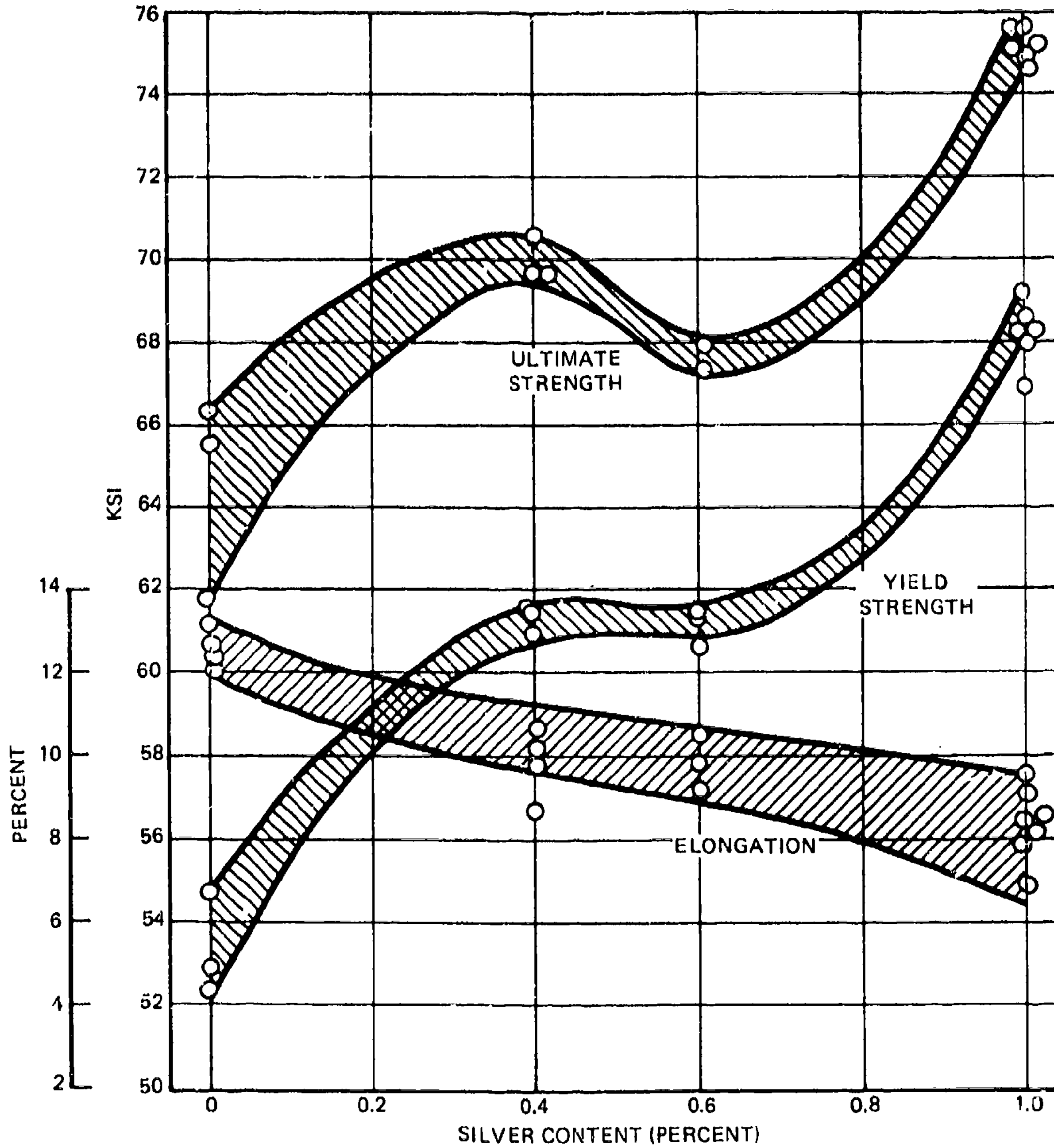


FIGURE 56. EFFECT OF SILVER CONTENT ON THE TENSILE PROPERTIES OF SHELL INVESTMENT CAST A201-T7

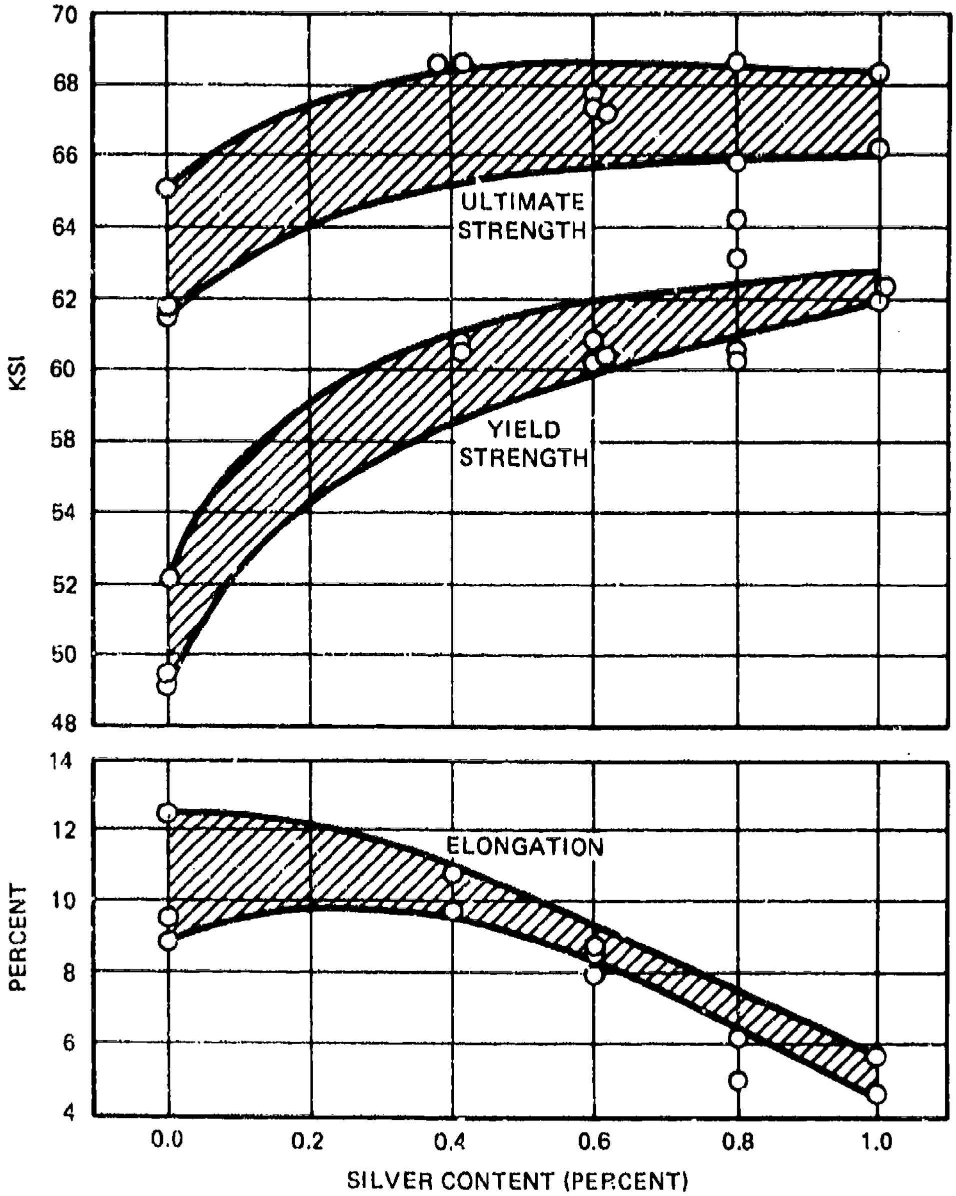


FIGURE 57. EFFECT OF SILVER CONTENT ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A201-T7

(4) Iron

Increasing iron contents reduced the ultimate and yield strengths of investment process plates but had little effect on the ductility which varied from 7 to 4 percent. However, the higher ductility of the sand composite molded plates was reduced from 11 percent to 5 percent with increasing iron contents. The ultimate and yield strengths of sand composite molded plates did not vary significantly with changing iron contents. These results are shown in Figures 58 and 59. The effect of high iron content to form a needlelike constituent in the microstructure is shown in Figure 60.

(5) Silicon

The effect of silicon is shown in Figures 61 and 62. Strength of the sand composite and investment molded plates was improved with an increase of silicon from 0.05 to 0.11 percent but, ductility was significantly reduced. High silicon content is reported to lower the nonequilibrium eutectic temperature of the alloy. This makes the alloy more vulnerable to incipient melting during solution heat treatment. It has been suggested that the silicon eutectic is a quarternary compound of Al-Cu-Mg-Si which melts at about 930F (Reference 13).

b. Heat Treatment

The heat treat process variables evaluated were:

1. Solution time
2. Quench water temperature
3. Age delay period
4. Artificial aging time.

Tensile specimens were excised from sand composite and shell investment plates which represented each of the variables. The results were plotted to determine the significance of each variable on the tensile properties of the alloy.

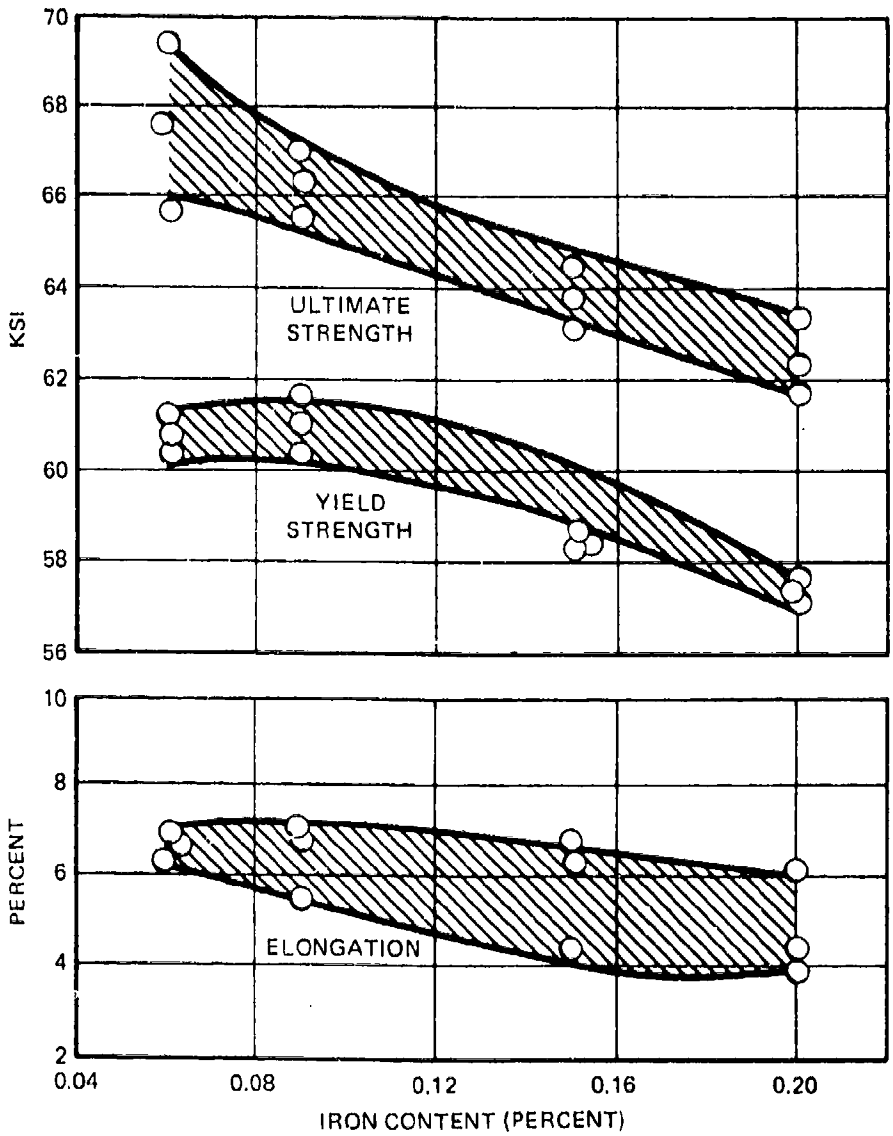


FIGURE 58. EFFECT OF IRON CONTENT ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A201-T7

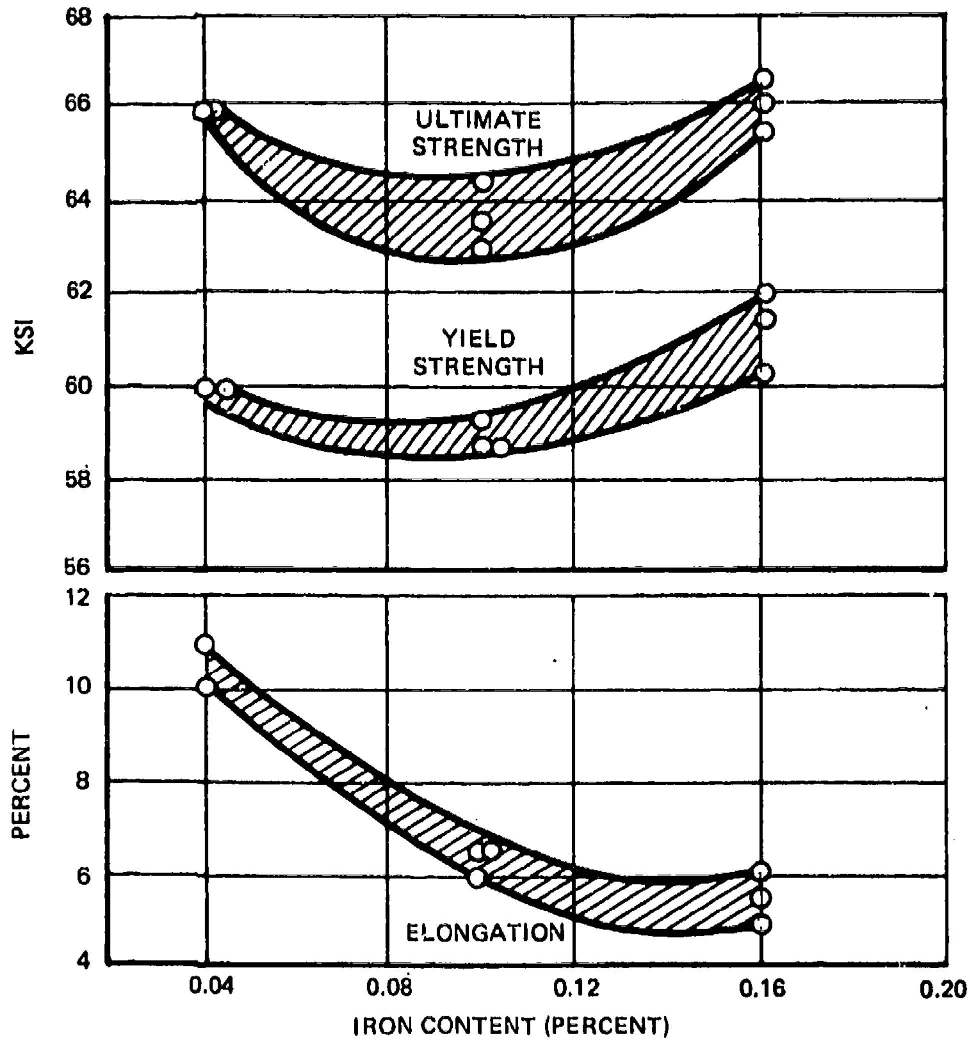
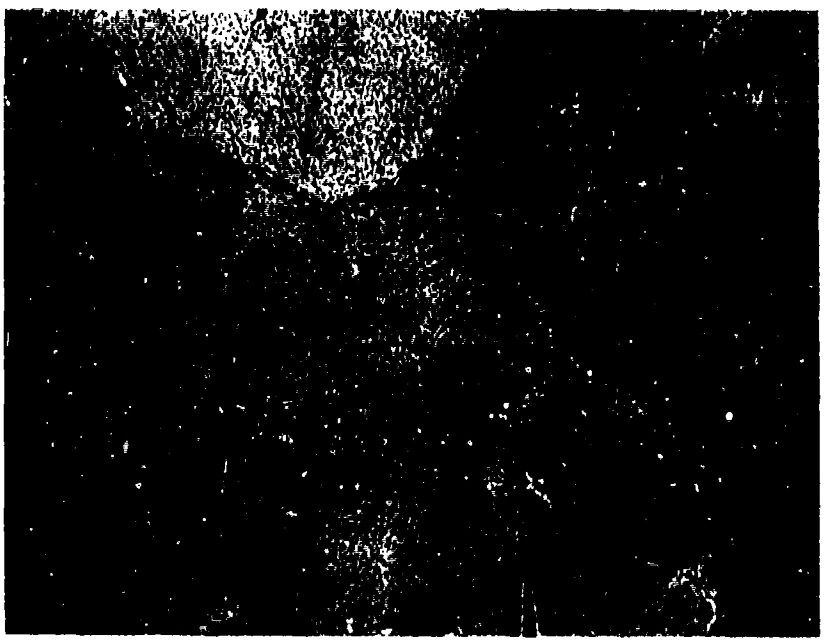


FIGURE 59. EFFECT OF IRON CONTENT ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A201-T7

KELLERS ETCH 0.20 PERCENT IRON 85-00237-23A



KELLERS ETCH 0.03 PERCENT IRON 85-00237-23B

FIGURE 60. EFFECT OF IRON CONTENT ON A201-T7 MICROSTRUCTURE

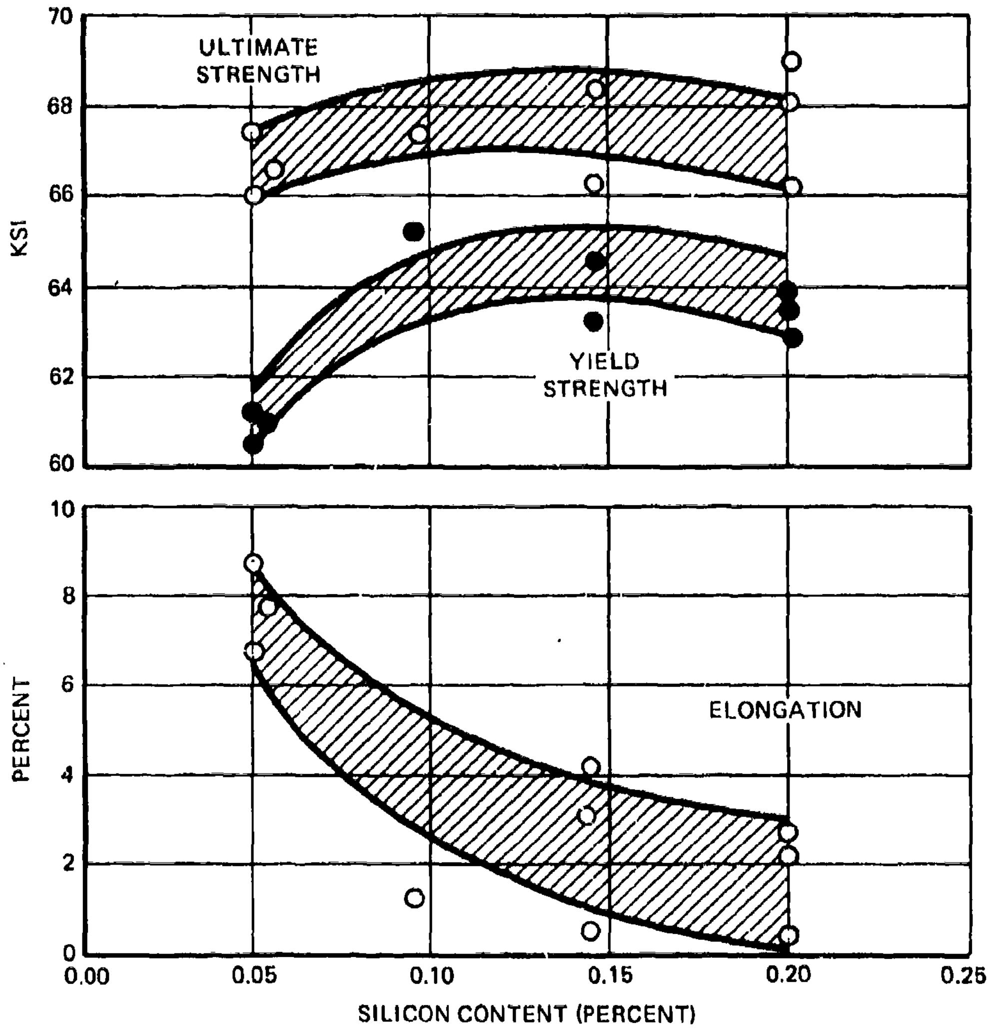


FIGURE 61. EFFECT OF SILICON CONTENT ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A201-T7

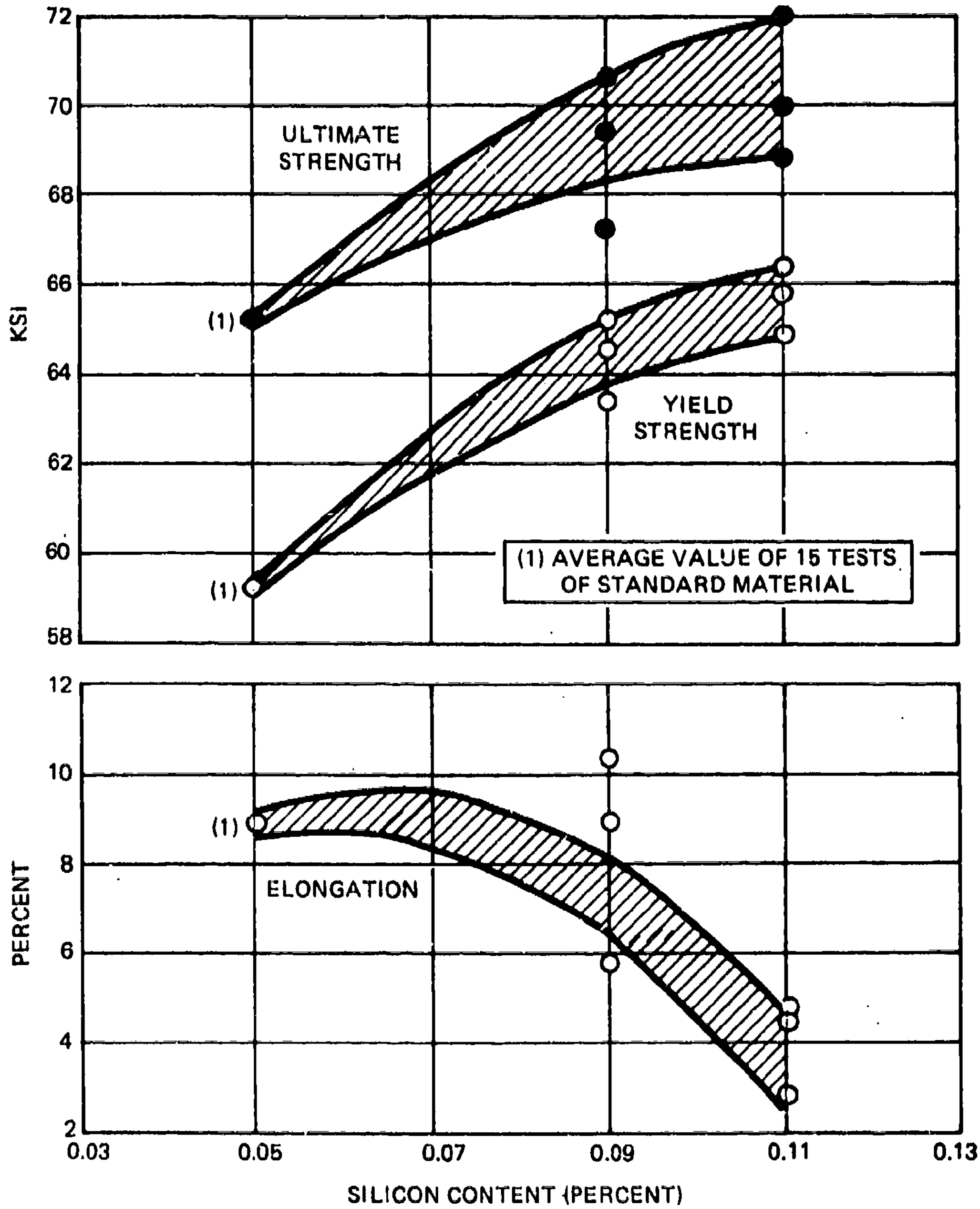


FIGURE 62. EFFECT OF SILICON CONTENT ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A201-T7

(1) Solution Time

In this investigation the solution time periods at 985F were six, twelve, and eighteen hours. The effect of this variation on the tensile properties resulted in minor improvements in ductility with the longer solution times (Figures 63 and 64).

(2) Quench Water Temperature

The quench water temperatures investigated varied from 40 to 212F. Increasing the quench water temperature resulted in a minor loss of properties (Figures 65 and 66). Although the effect on resistance to stress corrosion cracking was not determined, there is evidence that slower quench rates may relate to less stress corrosion cracking resistance.

(3) Delay Period at Ambient Room Temperature

The age delay periods investigated were zero, one-half, one, three, and five days (Figures 67 and 68). After a one-day delay, the strength and ductility of the sand composite molded plate showed significant improvement. Apparently the shell investment plate properties were not significantly affected by the delay period, but the small amount of data made this difficult to evaluate. No benefit was found after delay periods of one-half, one, three, and six days, followed by artificial aging to the T7 condition (Reference 14).

(4) Artificial Aging Time

In this investigation, artificial aging times of zero, three, five, and seven hours at an aging temperature of 370F were used (Figures 69 and 70). Artifical aging increased the tensile strength and decreased the ductility significantly. Overaging started after five hours causing the tensile strengths to decrease.

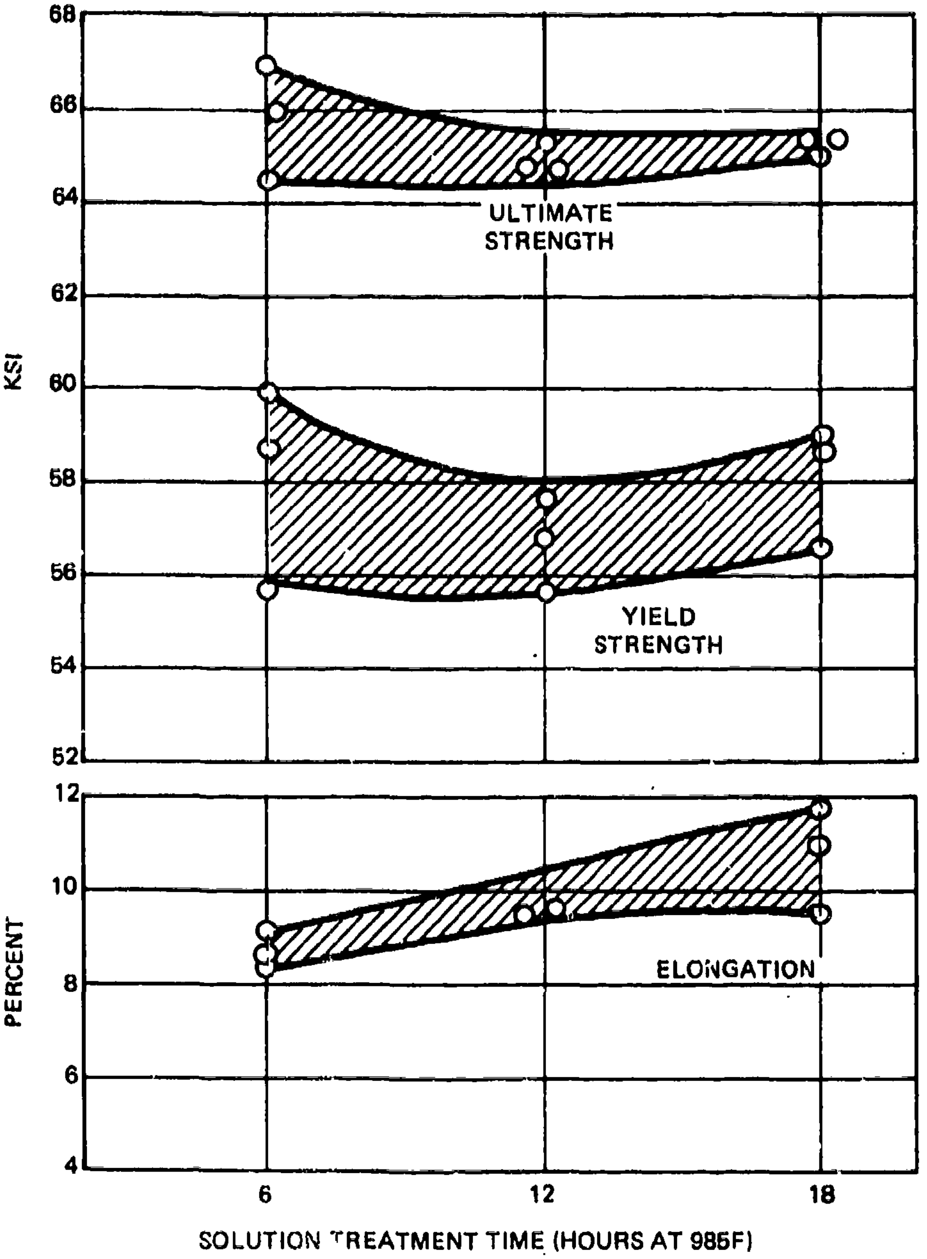


FIGURE 63. EFFECT OF SOLUTION HEAT TREATMENT TIME ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A201-T7

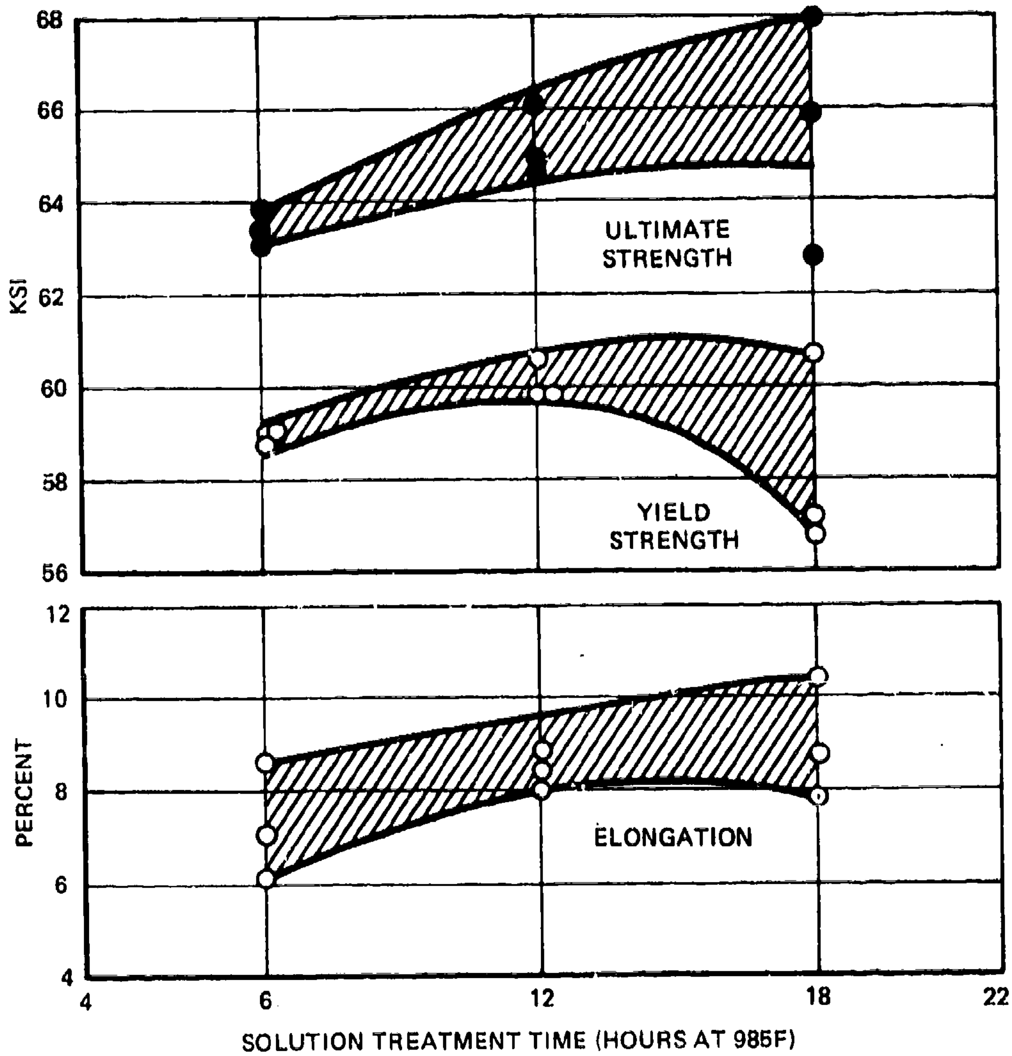


FIGURE 64. EFFECT OF SOLUTION HEAT TREATMENT TIME ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A201-T7

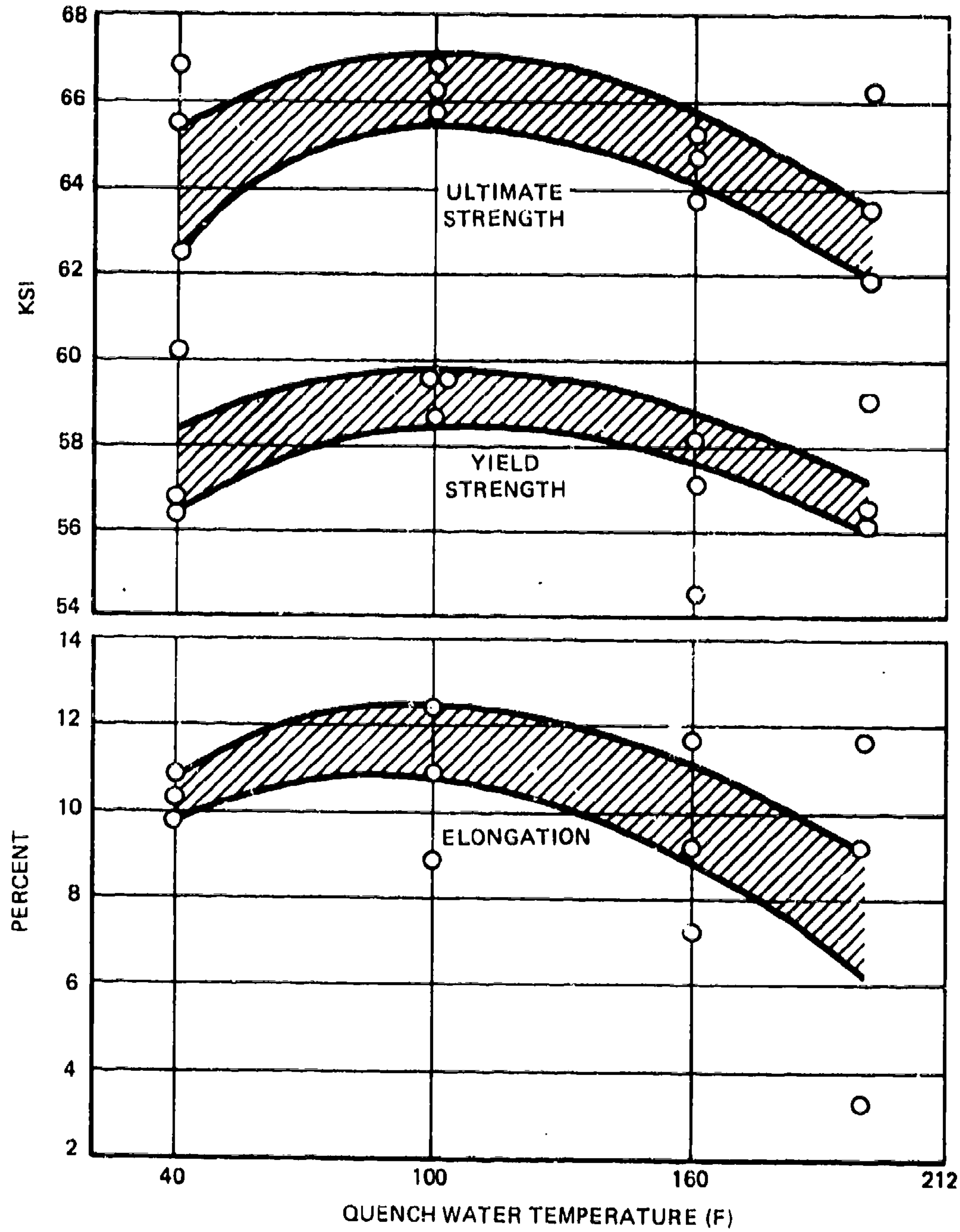


FIGURE 65. EFFECT OF QUENCH WATER TEMPERATURE ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A201-T7

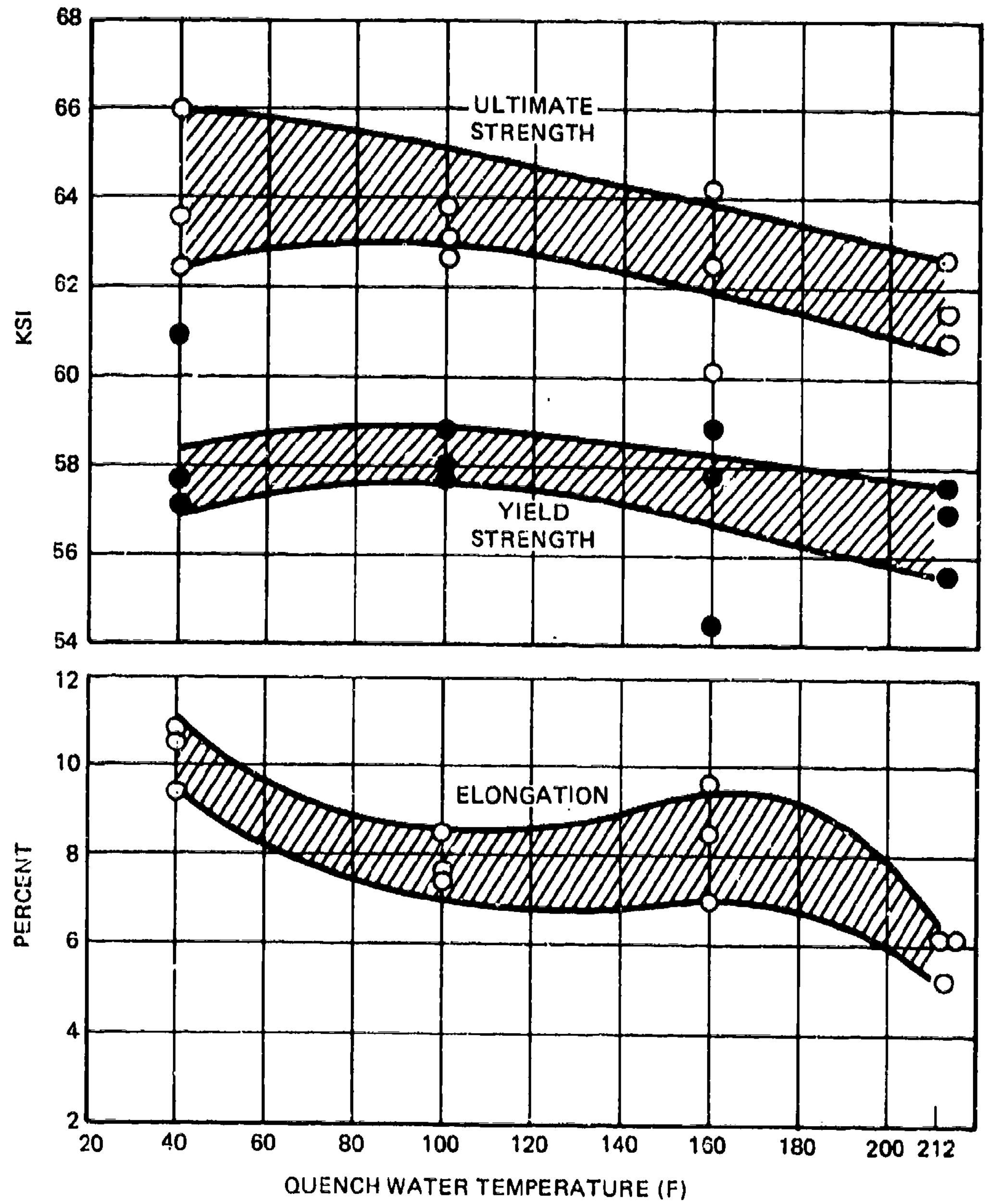


FIGURE 66. EFFECT OF QUENCH WATER TEMPERATURE ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A201-T7

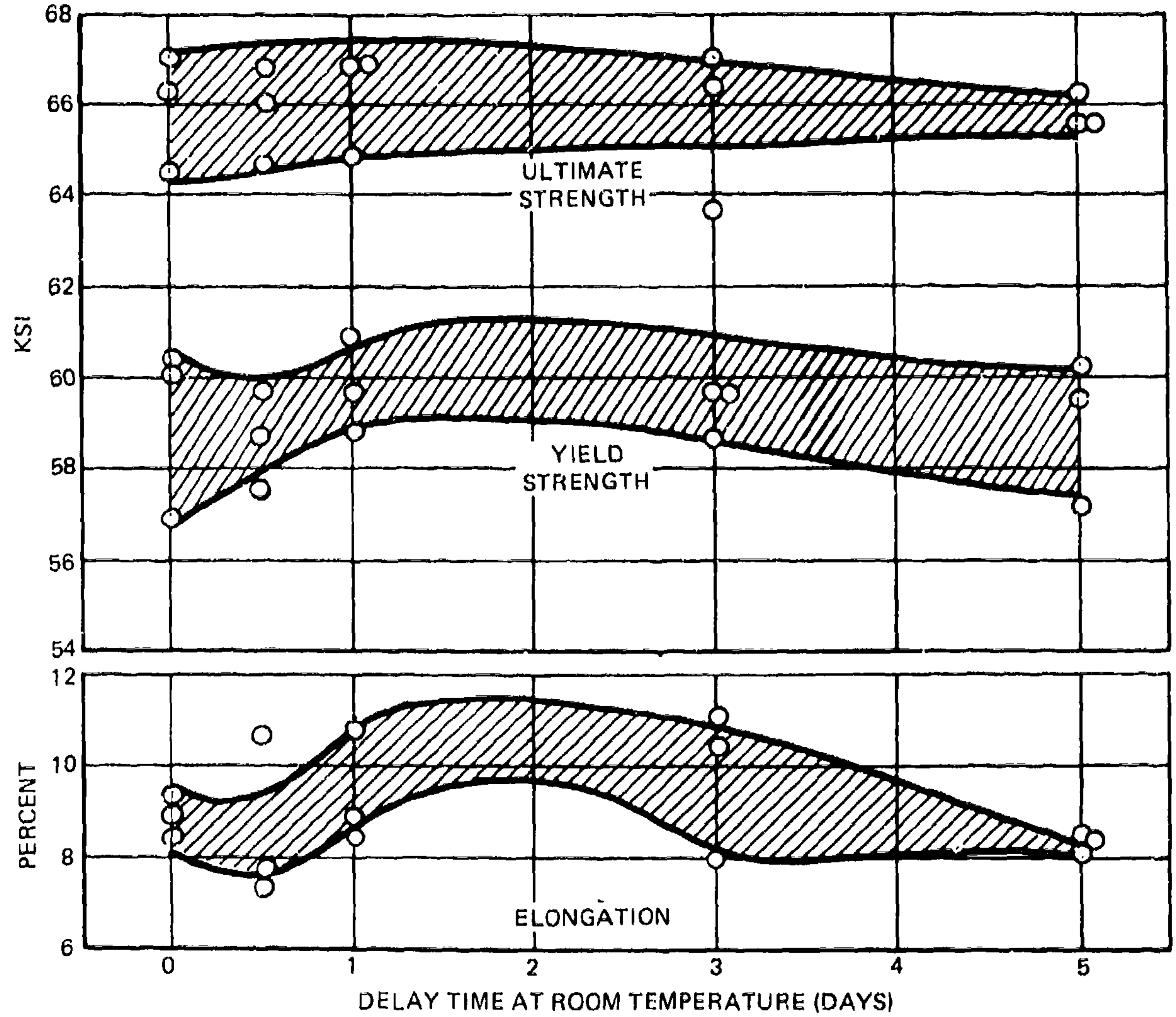


FIGURE 67. EFFECT OF DELAY TIME AT ROOM TEMPERATURE ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A201-T7

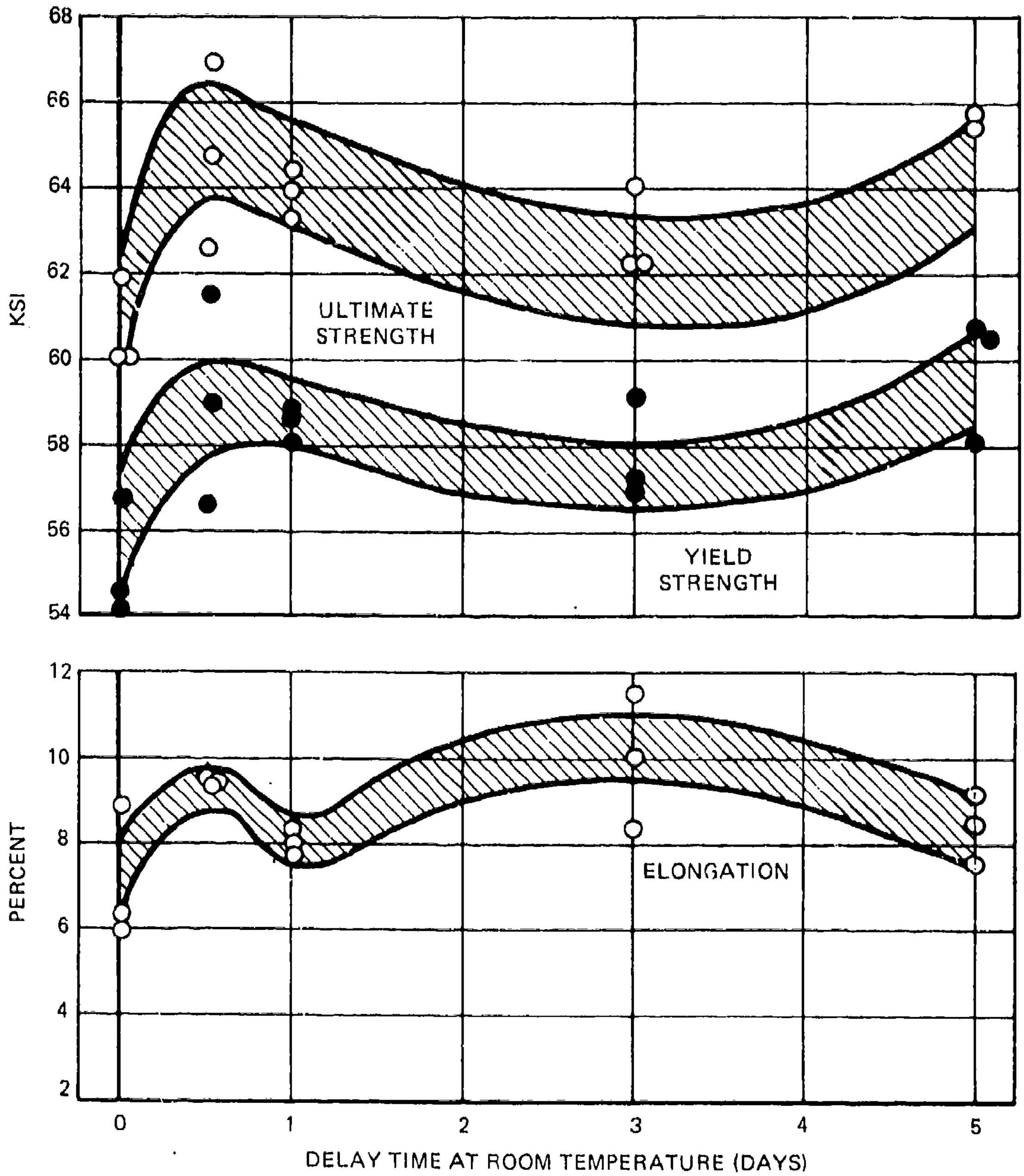


FIGURE 68. EFFECT OF DELAY TIME AT ROOM TEMPERATURE ON TENSILE PROPERTIES OF SAND COMPOSITE CAST A201-T7

c. Grain Size

Grain size was varied by changing the solidification rate and the procedure for adding grain refiner to the melt. In the sand composite molding process, changes in grain size were made by varying the amount of metal chill included in the mold (Figure 71). Grain size variations in the shell investment molds were controlled by the temperature of the shell. For comparison, the grain size of A201 plates was also varied by changes in the grain refining melt procedure (Figures 72 and 73).

Smaller grains produced significant improvement in ultimate strength and ductility of shell investment cast plates. This was most evident between 0.0020-and 0.0030-inch grain size although the data was widely scattered (Figures 74 and 75). Changes in grain size between 0.0030 to 0.0060 inches did not significantly affect the tensile properties. The ductility and ultimate strength of the sand composite plates were also significantly reduced when the grain size was increased from 0.0020 to 0.0030 inches. The yield strength was not affected.

d. Radiographic Quality

Two levels of radiographic quality was evaluated. The highest quality level was equal to, or better than, a Grade B per MIL-C-6021. This represented the highest quality available for production castings and is usually required in high-stress areas of premium quality castings. The lower qualities investigated were Grades C and D in accordance with MIL-C-6021 grade definition. The types of radiographic defects evaluated were:

1. Dross (less dense material)
2. Shrinkage sponge.

The tensile properties of specimens representing the two general levels of radiographic quality are shown in Figures 76 and 77. Generally, when the quality level was reduced the ultimate strength and ductility decreased significantly, although the yield strength was also reduced when the dross content of the sand composite plates was increased.

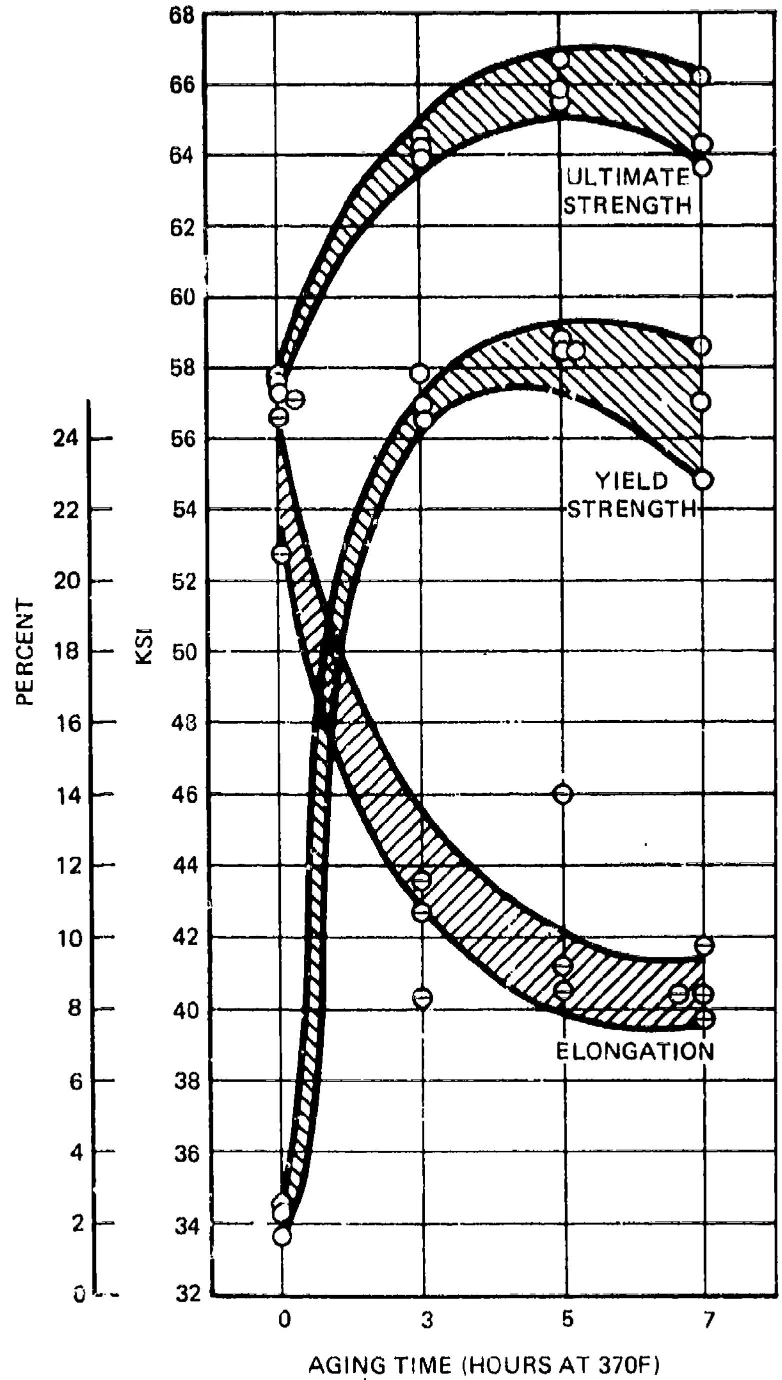


FIGURE 69. EFFECT OF ARTIFICIAL AGING TIME ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A201-T7

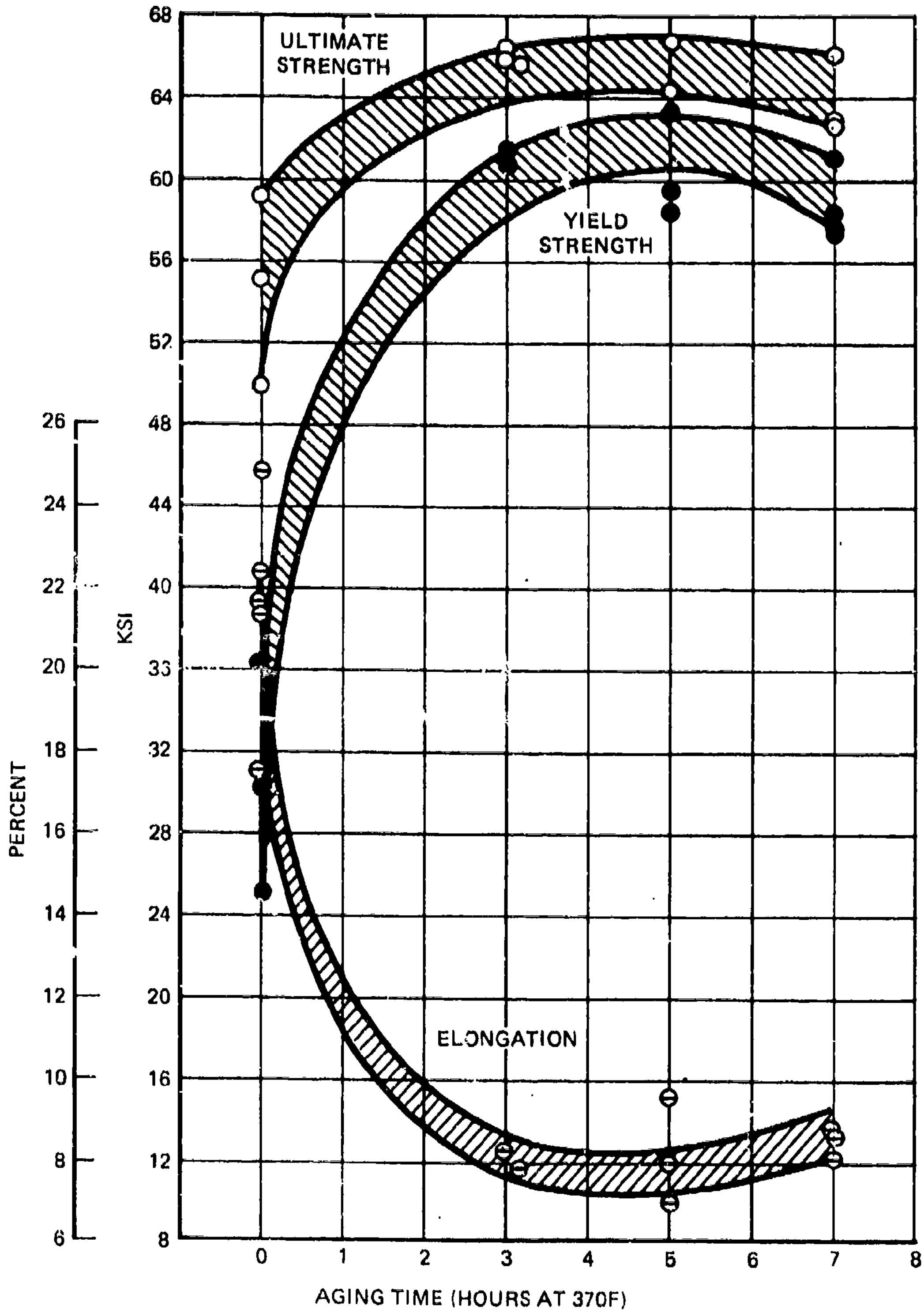
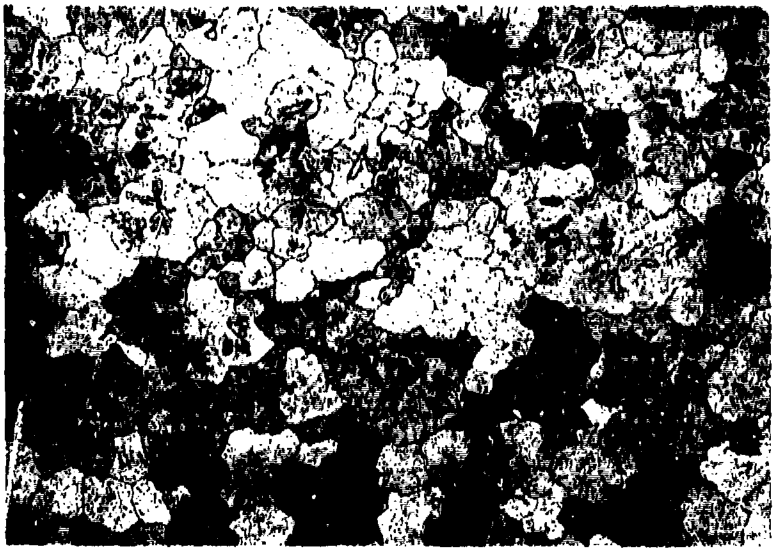


FIGURE 70. EFFECT OF AGING TIME ON THE TENSILE PROPERTIES OF SAND COMPOSITE CAST A201-T7

GRAIN SIZE, 0.0025 INCH
TENSILE, 67-59-10
MOLD CONTAINED COPE
AND DRAG CHILLS



86-00237-25A

GRAIN SIZE, 0.0040 INCH
TENSILE, 63-60-3
NO CHILLS USED

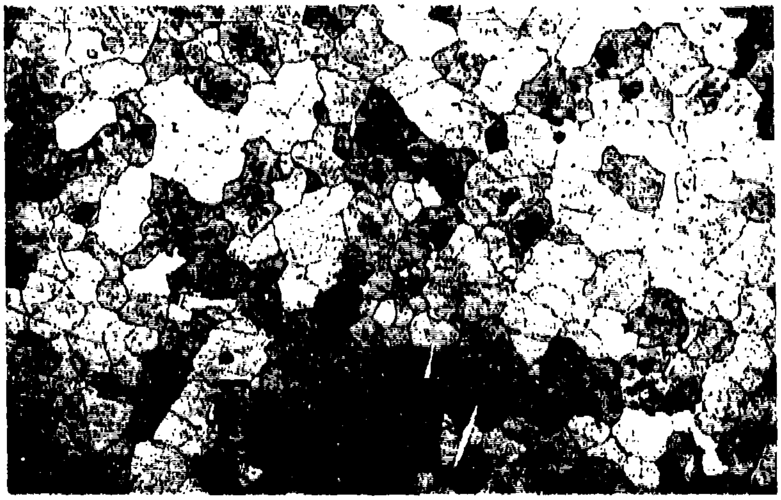
BOTH X100, KELLER ETCH

85-00237-25B

FIGURE 71. EFFECT OF CHILLS ON THE GRAIN SIZE OF SAND CAST A201-T7

GRAIN SIZE, 0.0019 INCH
TENSILE, 64-58-6

STANDARD PROCEDURE,
TI-B ADDITIONS MADE
'EARLY' AND 'LATE'



85-00238-10A

GRAIN SIZE, 0.0025 INCH
TENSILE, 64-58-4

TI-B ADDITION MADE
'EARLY' ONLY

85-00238-10B

GRAIN SIZE, 0.0038 INCH
TENSILE, 61-59-2

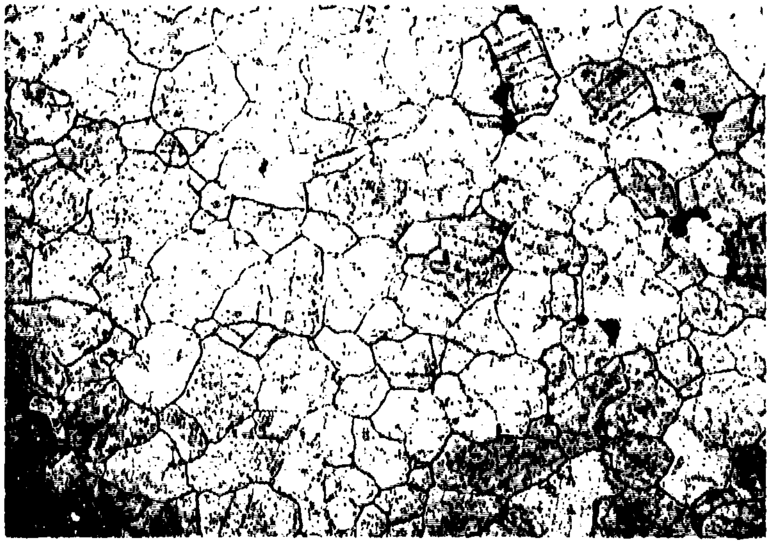
NO TI-B ADDED

ALL X100, KELLER ETCH

85-00238-10C

FIGURE 72. EFFECT OF TITANIUM-BORON GRAIN REFINER ADDITION ON THE GRAIN SIZE OF SAND COMPOSITE CAST A201-T7

GRAIN SIZE 0.0027 INCH
TENSILE 63-54-8
STANDARD GRAIN REFINER
ADDITION, CAST IMMEDIATELY



85-00239-1A

GRAIN SIZE 0.0036 INCH
TENSILE 62-54-7

STANDARD GRAIN REFINER
ADDITION, BUT THE MELT
WAS HELD OVERNIGHT BEFORE
CASTING

BOTH X100, KELLER ETCH

85-00239-1B

FIGURE 73. EFFECT OF GRAIN REFINER PROCEDURE ON THE GRAIN SIZE OF SHELL INVESTMENT CAST A201-T7

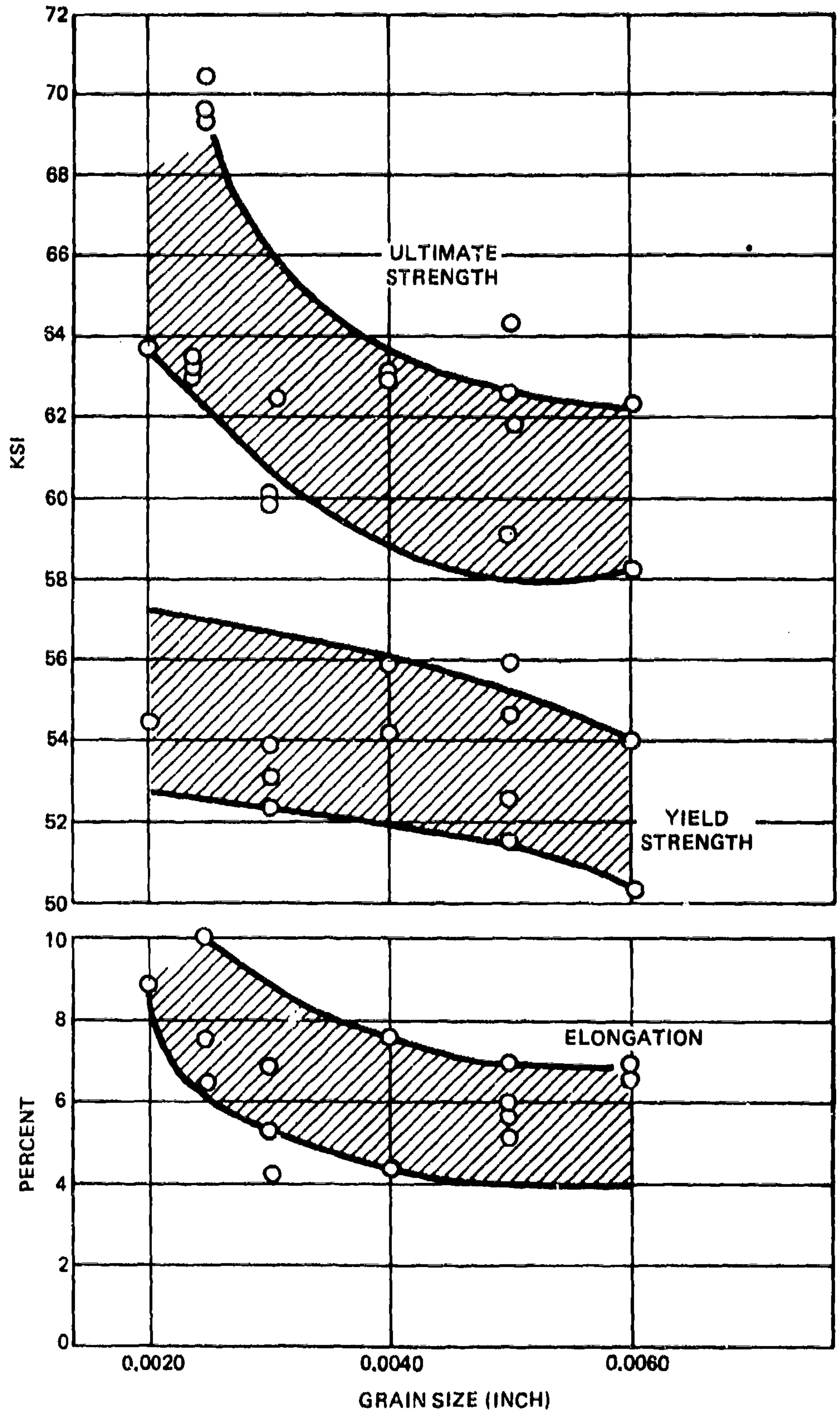


FIGURE 74. EFFECT OF GRAIN SIZE ON THE TENSILE PROPERTIES OF SHELL INVESTMENT CAST A201-T7

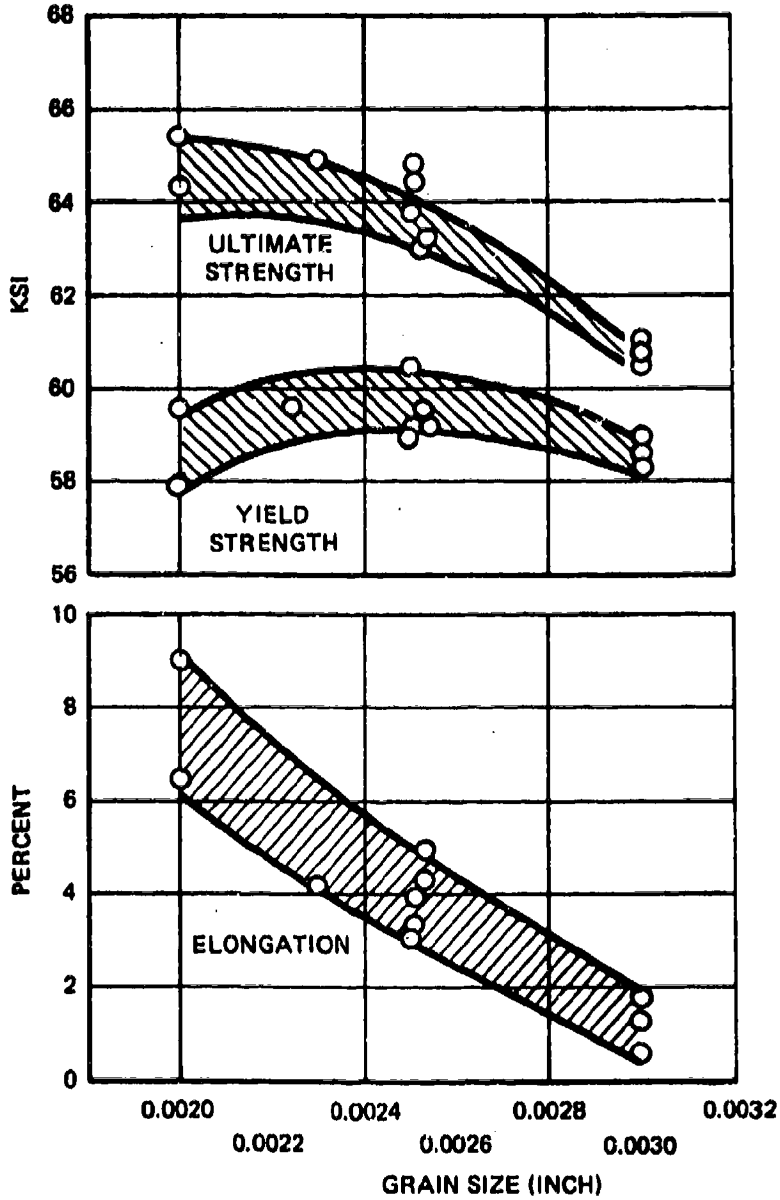


FIGURE 75. EFFECT OF GRAIN SIZE ON THE TENSILE PROPERTIES OF SAND CAST COMPOSITE CAST A201-T7

4. EFFECT OF PROCESS VARIABLES ON ELECTRICAL CONDUCTIVITY AND HARDNESS

Electrical conductivity, as measured in terms of percent International Annealed Copper Standard (percent IACS), and Rockwell hardness tests, were made on each sand composite and shell investment plate or tensile specimen excised from the plate. The results from the heat treatment investigations have been plotted on graphs to help interpret their significance (Figures 78 through 83). As shown in these figures, both electrical conductivity and hardness appear to show a general correlation only with artificial aging times, irrespective of the casting method. Conductivity has been recognized as an indicator of the general heat treatment condition of A201 alloy. This trend appears to also hold true for A357 alloy.

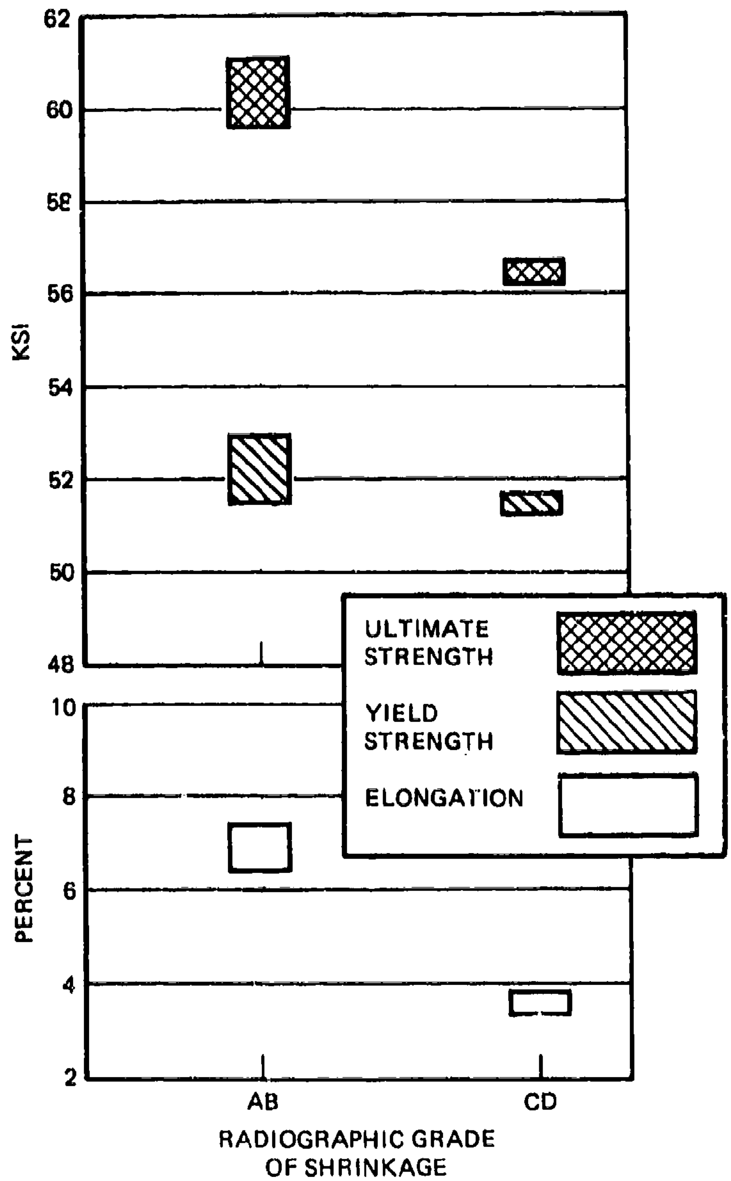


FIGURE 76. EFFECT OF SHRINKAGE AND DROSS ON TENSILE PROPERTIES OF SHELL INVESTMENT CAST A201-T7

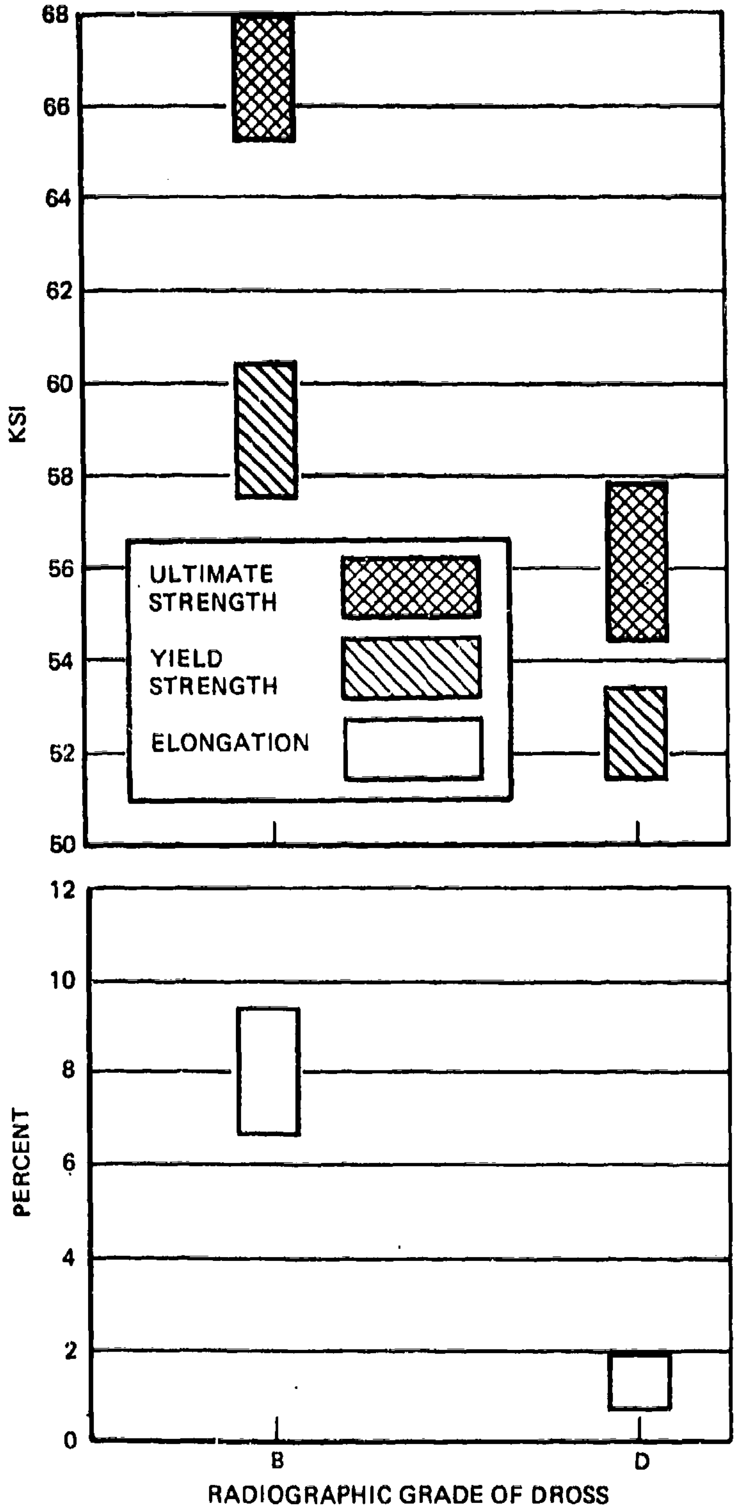


FIGURE 77. EFFECT OF DROSS ON THE TENSILE PROPERTIES OF SAND COMPOSITE CAST A201-T7

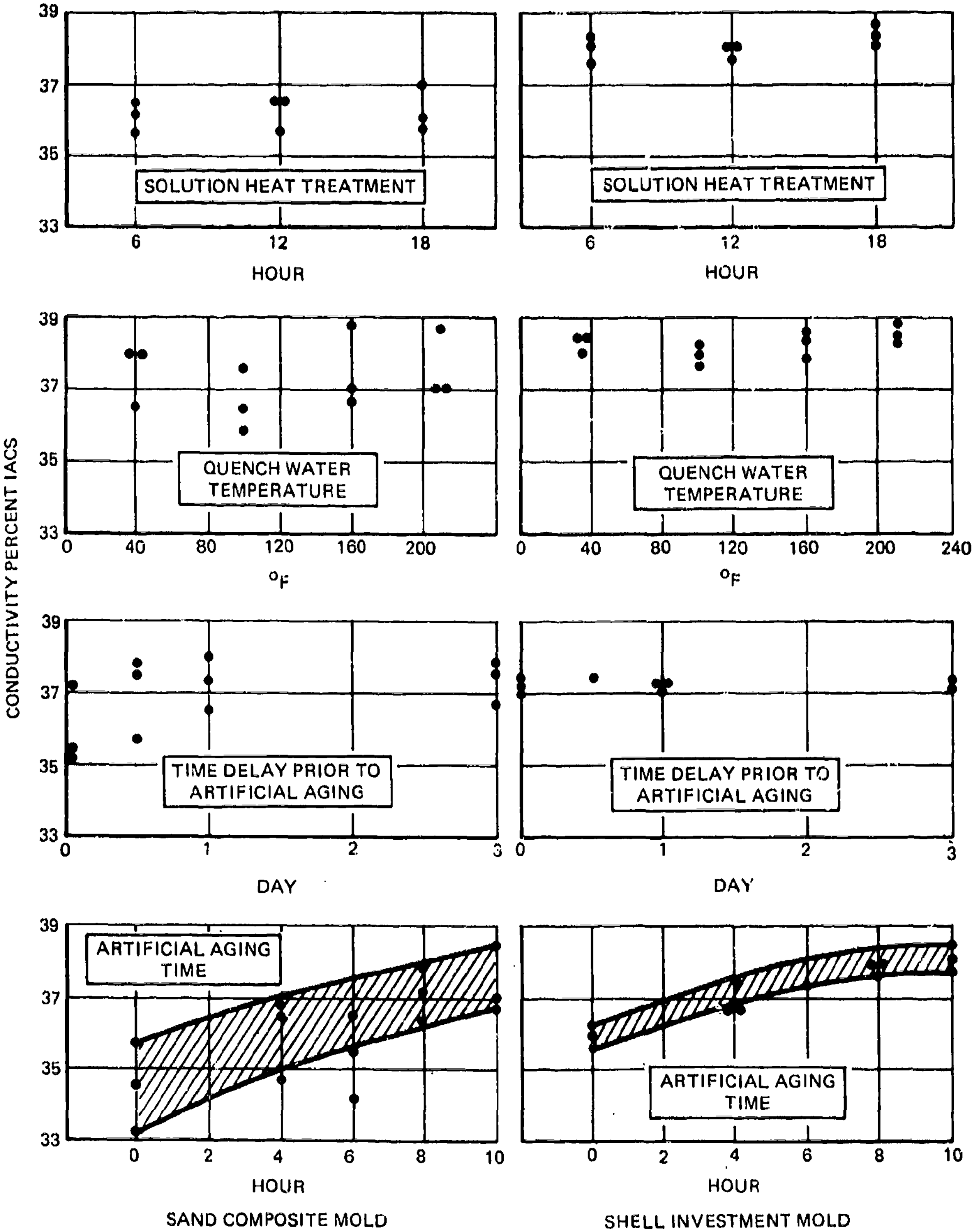


FIGURE 78. EFFECT OF HEAT TREATMENT VARIABLES ON CONDUCTIVITY OF A357-T6

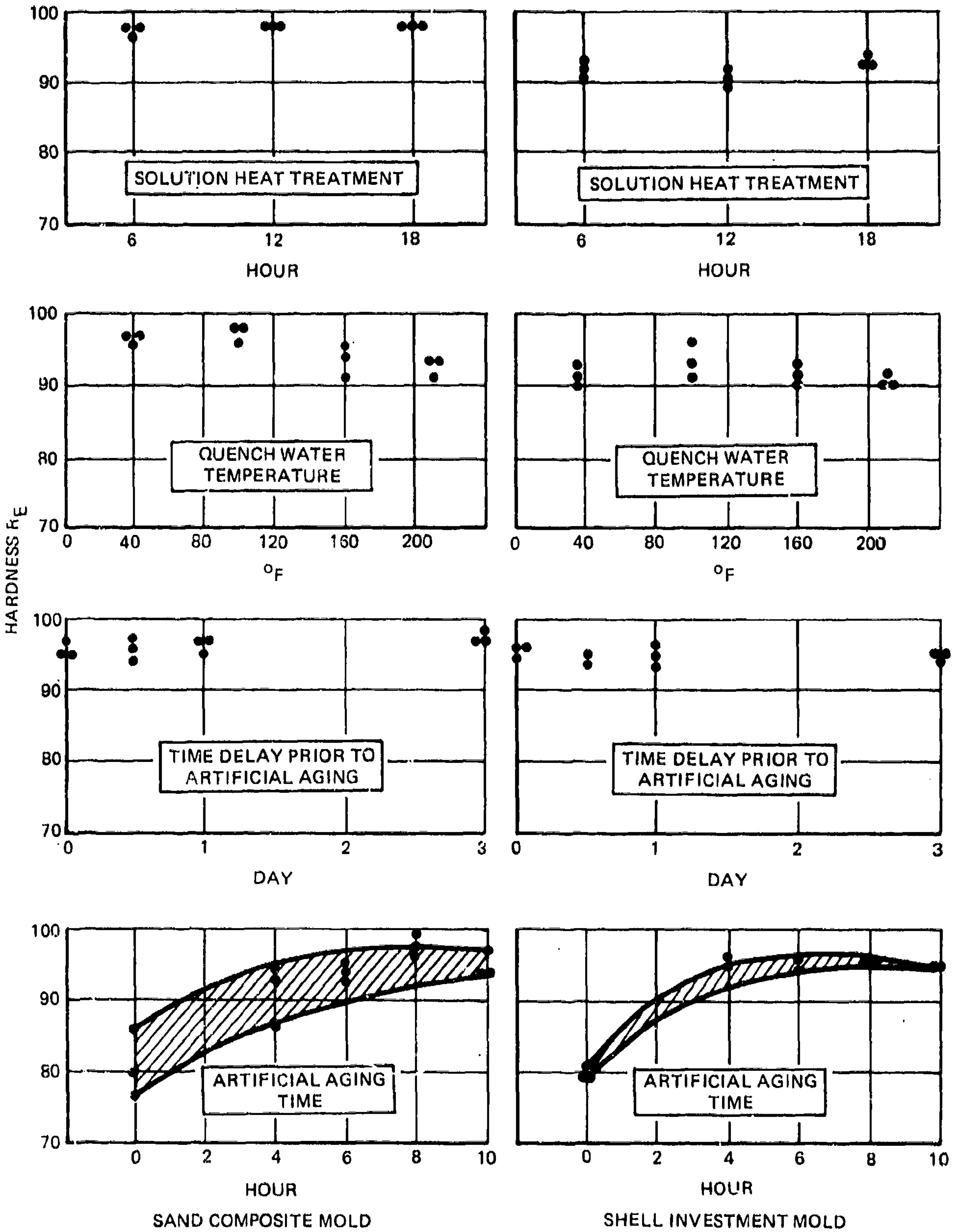


FIGURE 79. EFFECT OF HEAT TREATMENT VARIABLES ON HARDNESS OF A357-T6

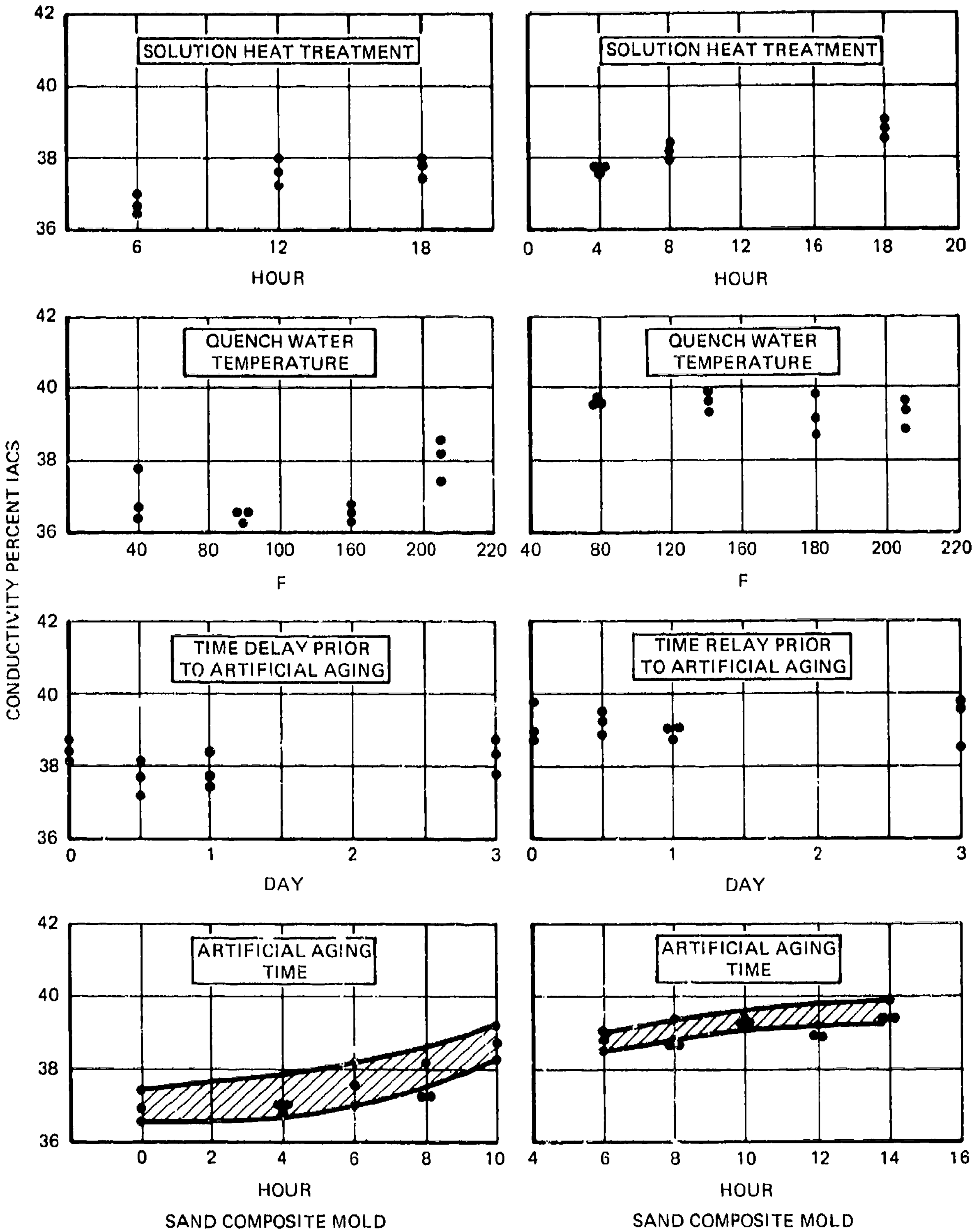


FIGURE 80. EFFECT OF HEAT TREATMENT VARIABLES OF CONDUCTIVITY OF A356-T6

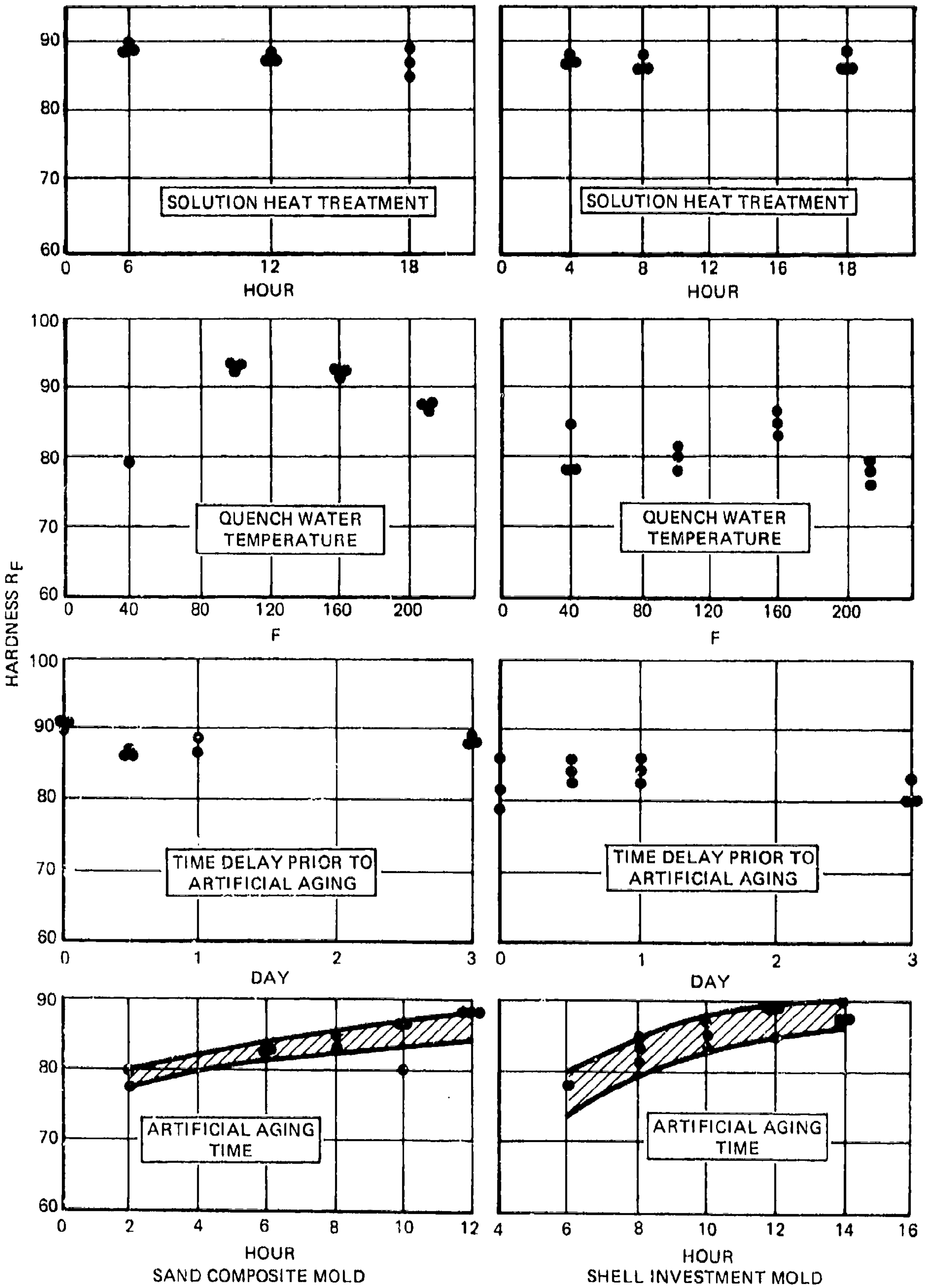


FIGURE 81. EFFECT OF HEAT TREATMENT VARIABLES ON HARDNESS OF A356-T6

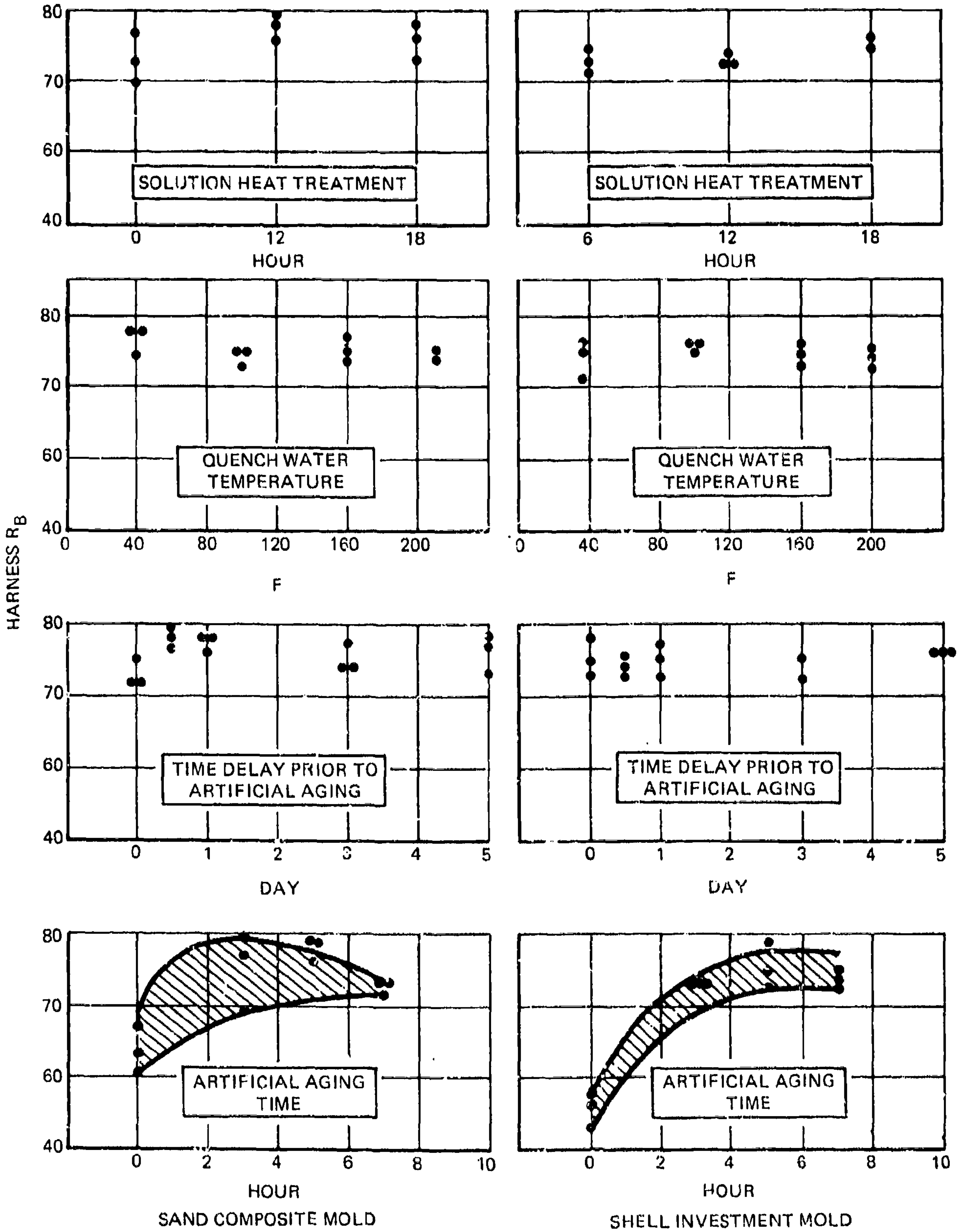


FIGURE 82. EFFECT OF HEAT TREATMENT VARIABLES ON HARDNESS OF A201-T7

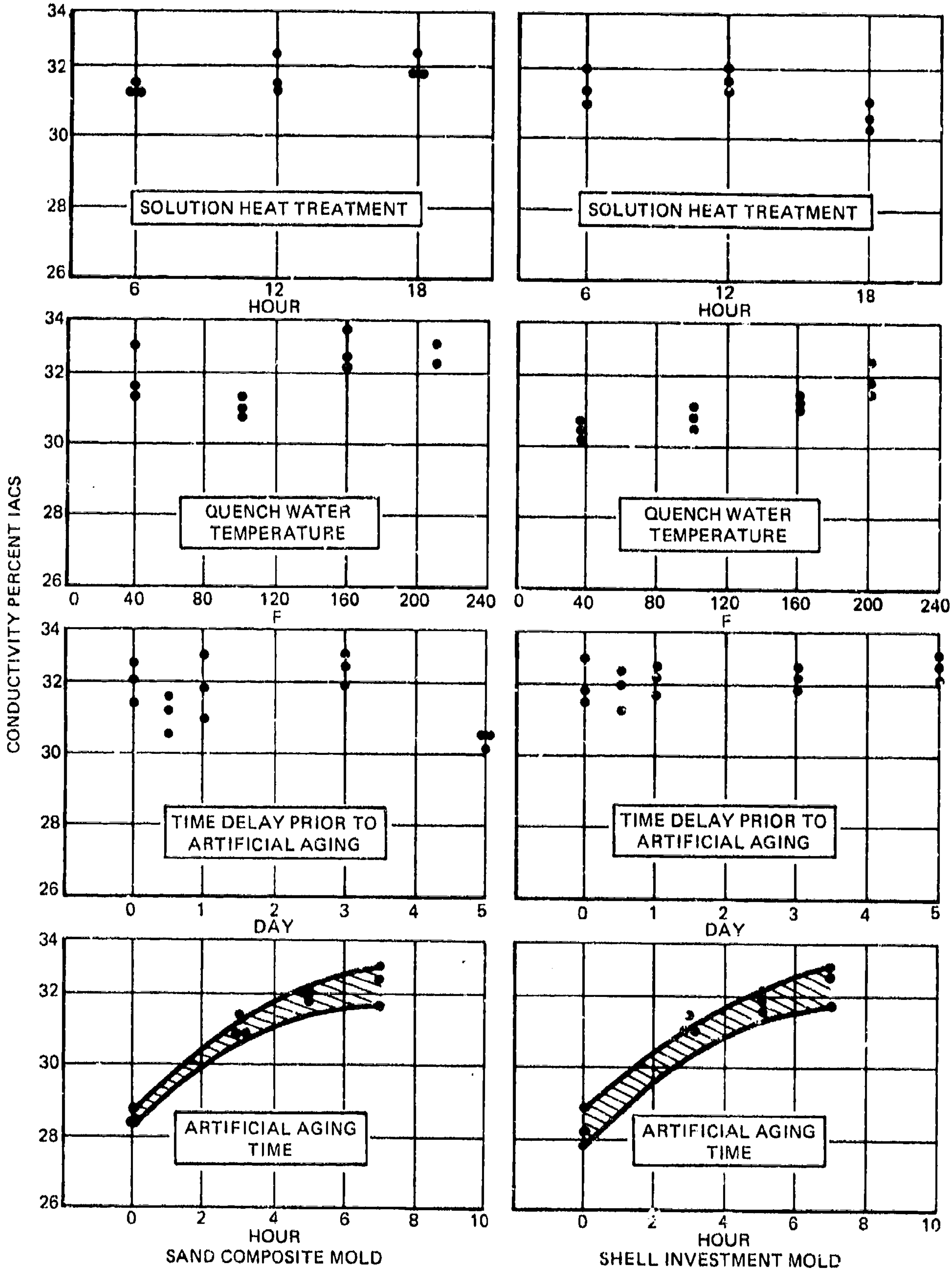


FIGURE 83. EFFECT OF HEAT TREATMENT VARIABLES ON CONDUCTIVITY OF A201-T7

SECTION VIII

OPTIMIZATION OF FOUNDRY PROCESSES AND DOCUMENTATION

1. OPTIMIZATION OF FOUNDRY PROCESS CONTROLS

An evaluation of processing variables indicated that the following variables require close foundry control to obtain consistently high tensile properties.

a. Melt Composition

Variations in alloy content show corresponding changes in tensile properties; therefore, control of alloy composition is an important factor in processing. The effect of minor variations in composition can be compensated by modifying heat treatment procedures; however, production schedules are best met when such composition variation is minimized so that castings of several melts can be heat treated in a single lot.

b. Melt Gas Content

Because of the affinity of molten aluminum to hydrogen, the melting procedure requires close control of the hydrogen content in the melt to prevent formation of gas porosity during solidification of the casting. Various types of equipment are used to monitor the hydrogen content of the melt. The procedure must be defined and followed for uniform results.

c. Melt Temperature

A sequence of events related to the melt temperature occurs chronologically in the melting process; therefore, it is necessary that melt temperature be controlled during melt preparation and at the time of pour. Melt temperature must be controlled to produce consistently high quality castings. Pouring temperature of the melt has a significant effect on the solidified structure of the casting, and therefore, to ensure consistent casting soundness and quality, the pouring temperature must be carefully controlled to

within a few degrees.

d. Molding Materials and Assembly

A sand composite mold is required. This is an assembly of materials within a sand mold which is engineered to obtain the direction and rate of solidification required to optimize the quality of casting. If the type, size or location of the material in the sand mold is changed, the desired effect on casting quality and properties may not be obtained.

e. Gating and Risering System

To obtain the desired casting quality, the gating and risering system is designed as an integral part of the molding and pouring processes. The gating system transfers the molten metal where it is needed with minimum loss of temperature and minimum turbulence. Risers maintain a reservoir of molten metal to fill voids that occur because of volumetric shrinkage.

Close control of mold assembly, pouring temperature, gating, and risering is necessary for consistent results. Thus, permanent gating and risering systems must be rigged on the casting pattern before production is initiated.

f. Heat Treatment

Good heat treatment procedures must be rigorously followed to take maximum advantage of the capability of the material. Procedures are necessary to define each step of the heat treatment, particularly the times, temperatures, load density, quenching procedure, and, in some instances, the aging delay time. Although these process variables must be controlled, the procedures will vary for any particular configuration depending on the specific equipment and skills of each foundry. It is important that the foundry document these procedures for each casting design.

2. OPTIMIZATION OF NDI TECHNIQUES

To determine the acceptability of optimum quality material by NDI techniques, various metallurgical features of the material that have a significant influence on the tensile properties were evaluated. Such features of A357 and A201 cast materials are radiographic quality, dendritic arm spacing (A357 only), and heat treatment response. The NDI methods for evaluating these characteristics are as follows:

Material Variable	Property Affected	Inspection Method	Test Procedure
Internal soundness	UTS, e	Radiographic inspection	MIL-STD-00453 Proposed AMS specification
Dendritic Arm Spacing (A357)	UTS, e	Relationship of DAS/UTS established by testing attached coupons	Proposed DAS specification Proposed material specification
Heat treat aging response	UTS, YS, e	Tensile test of attached coupon	ASTM E8 Proposed material specification

a. Internal Soundness

Existing radiographic procedures used to evaluate the internal soundness of a casting are described in MIL-STD-00453. The radiographic acceptance criteria are defined by several grades of quality A,B,C, and D in MIL-C-6021. Grade B is the minimum quality grade used for high stress areas of castings in critical applications.

It was demonstrated that tensile properties are severely reduced when the test material included areas less than Grade B quality. As the thickness of the material increases, the capability of the radiographic process to evaluate the material decreases. To control the flaw size within the material, a thickness limit of the material must be imposed or the radingraphic

procedure changed to obtain a higher sensitivity to detect flaws. Therefore, before a test casting configuration could be finalized, it was necessary to determine the maximum casting thickness which could be inspected for a Grade B radiographic quality.

In this program, both the thickness limit and radiographic procedure approaches were explored. The maximum thickness was judged to be just less than the transition thickness where Grade C quality appeared to change to grade B. The procedure used to determine the maximum material thickness is described in detail in Appendix C, along with the radiographic technique. The maximum thickness was determined by using cast plates of flawed material containing either gas porosity, sponge shrinkage, or dross that was judged by three NDI Level III inspectors to be of Grade C quality. The flawed material was placed within a stack of defect-free wrought plates to represent various thicknesses. Radiographs were taken in various increments of thickness until the quality of the flawed material in the stack appeared to change from a Grade C to a Grade B quality. The transition thickness varied, depending upon the type of flaw and the radiographic procedure used.

Three procedures were investigated to optimize the capability of the process. The first procedure was considered the standard process that would normally be used when MIL-STD-00453 is required. The second procedure differed primarily in the addition of a beryllium window to filter out low-frequency X-rays and thereby intensify the X-ray beam. In the third procedure, the exposure time was increased from 45 to 180 seconds. The results were as follows:

Procedure	Transition Thickness (inch)		
	Porosity	Shrinkage	Dross
Standard (std)	0.460	0.380	0.460
Std + Beryllium window	0.740	0.830	0.640
Std + 4x exposure	0.640	0.640	0.640

Since the transition thickness represented the thickness of material in which an apparent change to the higher quality level of Grade B was first noted, the maximum thickness in which the true quality was accurately visible was the prior thickness of the stacked plates. This thickness was as follows:

Procedure	Maximum Acceptable Thickness (inch)		
	Porosity	Shrinkage	Dross
Std	0.380	0.300	0.380
Std + Be window	0.640	0.740	0.540
Std + 4x exposure	0.540	0.640	0.540

These results indicate that material up to at least 0.540 inch thick can be accurately inspected by using either a beryllium window or 4x normal exposure time. Since the desired sensitivity can be obtained in various ways, the following requirements added to MIL-STD-00453 will provide the required capability:

1. Type I film
2. Maximum unsharpness value of 0.003 inch (0.08 mm)
3. Flaw sensitivity of 1 percent of the material thickness (1-2T).

b. NDI Method of Evaluating Microstructure Refinement (DAS)

The effect of microstructure refinement due to increased solidification rate is very important in obtaining optimum tensile properties of A357 alloy. As demonstrated in previous phases of the program, the more refined the structure, the smaller the DAS and the higher the tensile properties. However, the effect of the structure on tensile properties is relative, not absolute. Therefore, to evaluate the acceptability of the microstructure, a tensile property and DAS relationship must be established.

In this program, the acceptance limit for DAS of the microstructure of each casting was determined by evaluating two coupons attached to each casting. One coupon was heavily chilled and another was lightly chilled to provide a difference in the DAS structure of at least 0.0010 inch. The DAS value was determined on the surface of each coupon in accordance with the proposed specification included in Appendix H. If required, further acceptance determinations were obtained from a metallographic specimen excised from the tensile specimen that were taken from the attached coupons.

After the tensile properties of the attached coupon were determined, the DAS/UTS relationship was established and the maximum acceptable size DAS of the casting was determined for the minimum UTS required. The maximum acceptable DAS may be determined either by graphing the coupon results or by calculation. These procedures are included in the Appendix H. After the maximum DAS size was determined, random spot checks for DAS on the castings were used to determine acceptability. For uniformity, specific DAS test sites were chosen for production acceptance of test castings evaluated in the previous phase of the program.

Another approach to the evaluation was to use the relationship of DAS/UTS found in the qualification test castings. This relationship could be used to approximate a maximum DAS for all production castings. However, this approach is not believed to be as accurate as the approach described above, since variations in heat treatment may occur which will affect the DAS/UTS relationship. The value of establishing the DAS/UTS for each casting is that the effect of subtle variations in processing that occur from casting to casting are compensated for in the DAS/UTS relationship.

c. NDI Evaluation of Heat Treatment Aging Response

(1) A357 Alloy

The heat treat response can be evaluated for casting acceptability by determining the properties of a tensile specimen excised from a coupon attached to the casting. As demonstrated in Phase IB, variations in

heat treatment processing for solution treatment, quenching, or artificial aging, will affect the tensile properties of the material in its final aged condition. The yield strength of the material is more sensitive to heat treatment processing variables than is elongation or ultimate tensile strength. Soundness and microstructure coarseness do not significantly affect yield strength but do not affect ultimate strength and elongation. For this reason, an acceptable range of yield strength was selected to represent properly heat treated material. In addition to the yield strength range, a minimum ultimate strength equal to that required of the casting was required to be exhibited by the tensile specimen excised from the attached coupon. Properly processed material should exhibit a capability in the attached coupon to meet minimum ultimate strength values for the range of yield strength values established for heat treatment control. Hardness testing of A357 was also used to confirm that the material was aged to the T6 condition.

(2) A201 Alloy

The tensile properties of an attached coupon can be used to evaluate the heat treat response in a similar manner as A357 alloy except that (1) a yield strength range is not applicable and (2) a minimum elongation value is necessary. Since the aging procedure is defined in the specification to assure a T7 condition, only a minimum yield strength value is necessary to verify that the proper age was used. Hardness and electrical conductivity are also NDI tests which can be applied to provide assurance that the material was aged to the T7 condition. The minimum elongation value provides assurance that the grain refining procedures were adequate. A minimum ultimate strength requirement of the attached coupon confirms that the alloy content was sufficient to develop the necessary strength when properly heat treated. For these reasons, a minimum ultimate strength, yield strength, and elongation valued for the attached coupon are necessary.

3. PROPOSED MATERIALS PROCUREMENT SPECIFICATION

Preliminary specifications were updated to include the proposed NDI methods and foundry control factors. The primary differences between the proposed and the existing specification requirements of MIL-A-21180 are as follows.

a. Composition

The proposed specifications limit the alloy content to the high end of the composition range to assure high strength values. The alloy content differs from the military specification in the following manner:

	MIL-A-21180 (%)	Proposed (%)
A357 Alloy		
Magnesium	0.40 to 0.70	0.55 - 0.65
A201 Alloy		
Copper	4.00 to 5.00	4.50 - 5.00
Magnesium	0.15 to 0.35	0.25 - 0.35
Silver	0.40 to 1.00	0.50 - 1.00

b. Integrally Attached Coupons

The proposed specifications include the use of integrally attached coupons for heat treatment control and for establishing the DAS/UTS relationship in A357. Although the coupons do not necessarily represent the soundness or microstructure of the casting, the yield strength property of the coupons is representative of the casting. The DAS/UTS relationship of A357 castings, as determined from the integral coupons, is useful in verifying the solidification rate effect throughout the casting. The ultimate strength property of the coupon confirms that the alloy composition when properly heat treated has the necessary strength capability, and the elongation property of the attached A201 coupon confirms proper grain refinement in the material.

c. Radiographic Quality

The sensitivity required in MIL-A-21180 for determining unacceptable flaws is two percent of material thickness. The proposed specifications require a technique that will provide a sensitivity of one percent of the material thickness, a maximum limit of unsoundness not to exceed Grade B in designated areas using Type 1 film, and a maximum geometric unsharpness factor of 0.003 inch.

d. Penetrant Inspection for Surface Quality

For clarification purposes, a rejection criterion is included in the proposed specifications that will disallow any individual pore that is less than twice its maximum dimension to an edge or extremity of the casting or where the pores form a linear indication; that is, three or more pores in a line and the distance between each indication less than twice the maximum dimension of either adjacent indication.

Also, any indication that is five times longer than its width is considered a linear indication and therefore is rejectable.

The proposed specifications include a general statement similar to MIL-A-21180, which states that linear indications, cracks, cold shuts, and seams are causes for rejection.

e. Casting Identification

In the proposed specifications, each casting is required to be identified by a raised serial number, whereas MIL-A-21180 requires a raised heat number which may be the same for all castings poured over an eight-hour period.

SECTION IX

CASTING PROPERTY EVALUATION

1. INTRODUCTION

In this section, the following four tasks are reported:

1. Qualification Testing: Four foundries were selected to produce test castings for the determination of design property information for A357-T6 and A201-T7 sand composite molded castings. Preproduction sample castings were evaluated to determine the capability of the castings to meet target tensile properties.

2. Production and Acceptance Testing: Production castings from a minimum of five melts and two heat treatment lots from each foundry were inspected for acceptance using NDI procedures and criteria. All test results are presented in detail in this section.

3. Property Test Program: A testing program was devised to obtain sufficient specimens for MIL-HDBK-5 property analysis of each alloy, as well as damage tolerance and fatigue information from test castings. A limited amount of testing was included to determine the effect of weld improvement and radiographic unsoundness on casting properties.

4. Design Property Allowable Determination: The MIL-HDBK-5 analysis procedure was used for determining design properties. Battelle Columbus Laboratories performed the data analysis.

a. Selection of Foundries

Four foundries were selected for the production of test castings needed for design property determination. The four foundries selected represented small and large foundries that have previously used both alloys and the sand composite molding process to produce premium quality castings for military aerospace weapon systems. The selected foundries were:

Alloy A357 casting suppliers:

1. Magnesium Alloy Products Company
   Gardena, California
   Gerpreet Jaliwalia, Metallurgist

2. Teledyne Cast Products Company
   Pomona, California
   Emmett Bossing, Metallurgist

Alloy A201 casting suppliers:

3. Morris Bean and Company
   Yellow Springs, Ohio
   Charles Nelson, Metallurgist

4. Smithford Products Company
   Ontario, California
   Stan Warrington, Engineer

b. Test Casting Configuration

The evaluation of radiographic procedures showed that 0.5 inch is the maximum thickness that could be examined to ensure that Grade B acceptance size defects are not exceeded. Therefore, a section 0.5-inch thick was located within a step plate configuration to represent an isolated area of an aerospace configuration that required optimum tensile properties. The test configuration is shown in Figure 84. Various changes in thickness were included to increase the complexity of the configuration.

2. FOUNDRY PROCESS QUALIFICATION

a. General Procedure

The following procedure was used to qualify the process of each foundry. Three preproduction castings were submitted for qualification testing by each foundry.

(1) Target Tensile Properties (Minimum)

Tensile specimens excised from the casting were required to exhibit at least the following:

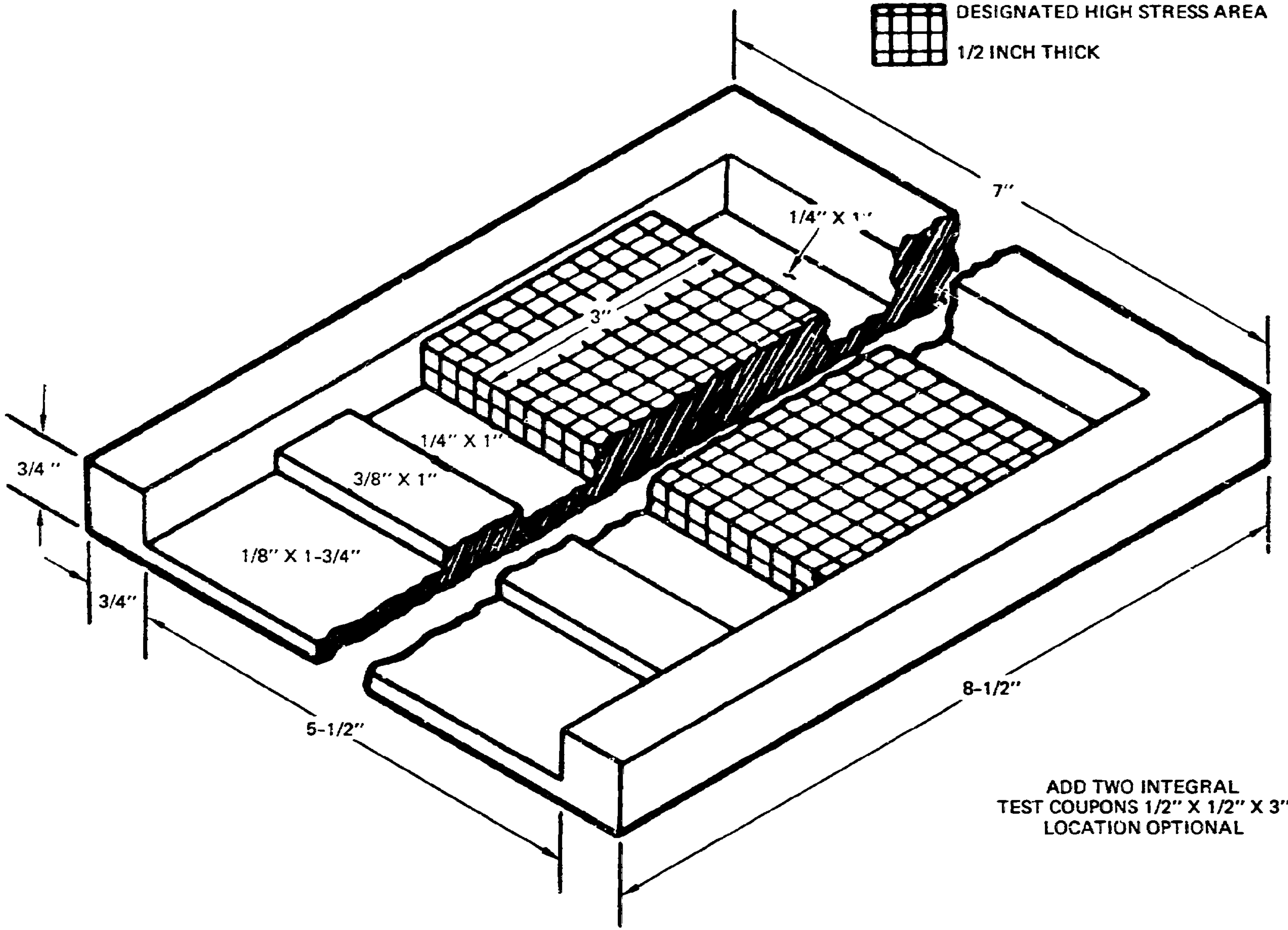


FIGURE 84. STEP PLATE CASTING

	UTS (ksi)	YS (ksi)	e (%)
A357 Alloy:			
Designated area	50	40	5
Nondesignated area	Grade C - radiographic quality		
A201 Alloy:			
Designated area	60	53	3
Non-designated area	Grade C - radiographic quality		

(2) Melt Composition

Melt samples taken at the foundry were required to conform to the following:

A357 Alloy:

Same as MIL-A-21180 except: Magnesium - 0.55-0.65%

A201 Alloy:

Same as MIL-A-21180 except: Copper - 4.50 to 5.00%
Silver - 0.50 to 1.00%
Magnesium - 0.25 to 0.35%

(3) Attached Coupons

A357 Alloy: Two coupons were attached to each casting and remained attached until removed by the inspection facility after all processing was completed. One of the two coupons was more heavily chilled to provide a minimum difference of 0.0010 inch of DAS between the two coupons. Target DAS values were 0.0010 to 0.0015 inch in the heavily chilled coupon. Tensile properties were determined for information only.

A201 Alloy: A minimum of two coupons were attached to each test casting and remained attached until removed by the inspection facility after all processing was completed. The tensile properties of one coupon were determined in each plate for information only.

(4) Miscellaneous Tests for Information Only

The following tests were performed for information only:

1. Hardness testing
2. Penetrant inspection
3. Electrical conductivity (A201 only).

(5) Fracture Toughness Block

A qualification requirement for the fracture toughness test block (Figure 85) was that an excised tensile specimen be capable of meeting the minimum target tensile properties agreed upon for the designated area of the step plate casting. (Separate blocks were cast for the fracture toughness test in an effort to obtain valid K_{Ic} values.)

b. Test Results, A357 Alloy

The results obtained from A357-T6 qualification tests of three step plates and one fracture toughness block submitted by each foundry are as follows:

(1) Tensile Properties

Supplier	Material	Tensile Properties of Specimens from Designated Area			
		Plate	UTS (ksi)	YS (ksi)	e (%)
Magnesium Alloy Products	Step Plates				
		1	53.7	44.7	8.9
		1	53.6	43.9	8.4
		1	54.9	45.9	8.8
		1	53.8	45.9	8.0

ADD TWO INTEGRAL
TEST COUPONS 1/2" X 1/2" X 3"
LOCATION OPTIONAL

	t (INCH)
ALLOY A357	0.88
ALLOY A201	1.20

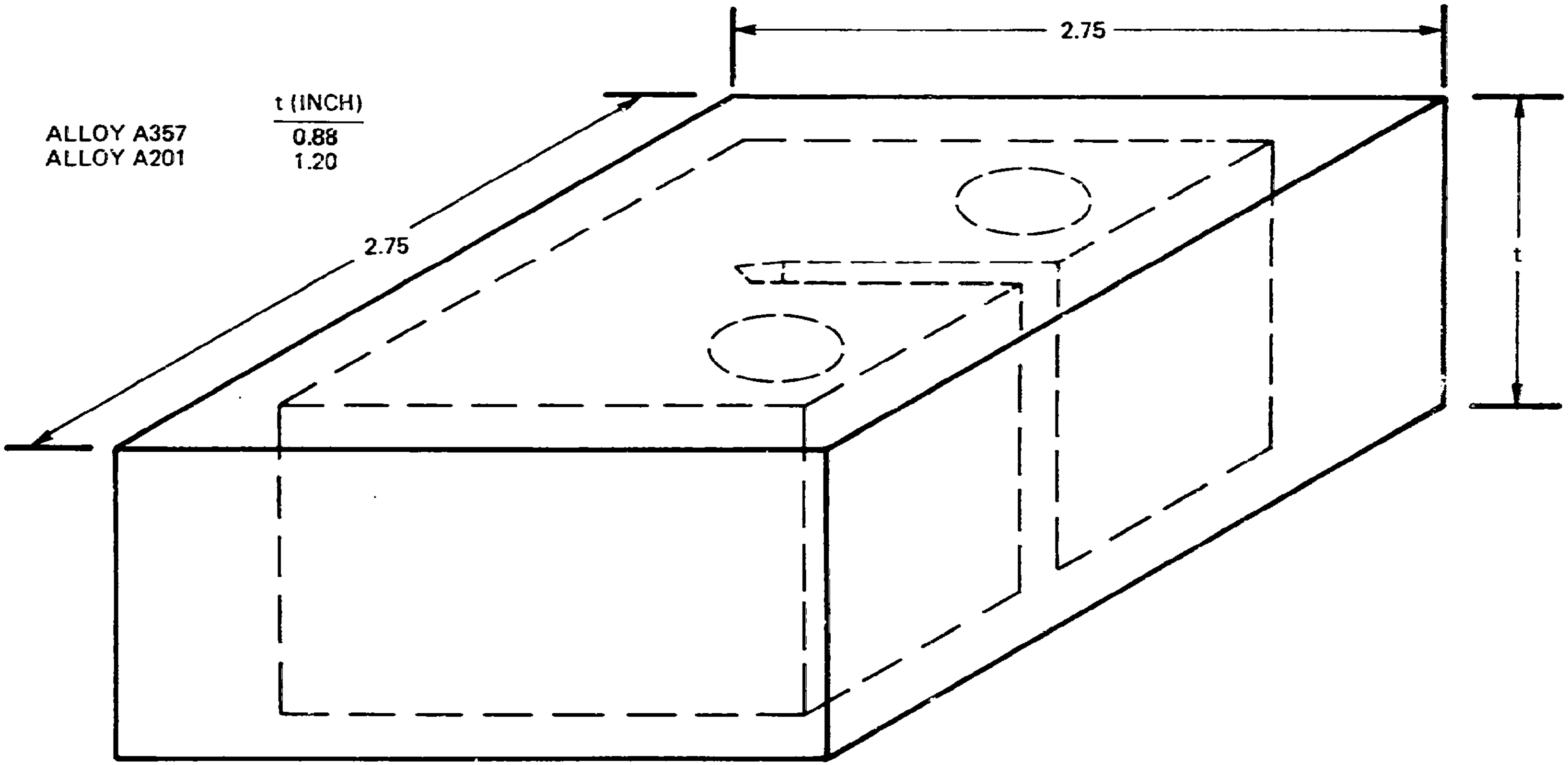


FIGURE 85. FRACTURE TOUGHNESS BLOCK CASTING

Supplier	Material	Tensile Properties of Specimens from Designated Area			
		Plate	UTS (ksi)	YS (ksi)	e (%)
Magnesium Alloy Products	Step Plates				
		1	54.4	46.8	7.4
		2	54.3	45.0	9.0
		2	54.1	44.4	10.2
		2	54.2	44.9	8.2
		2	54.3	46.5	5.6
		2	51.6	42.3	6.8
		3	53.2	42.7	8.5
		3	53.4	42.7	10.9
		3	54.0	45.3	6.8
	Minimum		51.6	42.3	5.6
	Maximum		54.9	46.8	10.9
	K_{Ic} test block		51.4	43.3	6.0

Supplier	Material	Tensile Properties of Specimens from Designated Area			
Teledyne Cast Products	Step Plates	Plate	UTS (ksi)	YS (ksi)	e (%)
		1	51.0	43.8	6.3
		1	50.1	45.6	4.2*
		1	52.1	43.9	9.9
		2	53.5	45.9	7.3
		2	53.4	46.5	6.7
		2	54.3	46.5	8.6
		2	51.7	46.5	5.3
		2	52.8	46.6	5.6
		2	50.8	45.1	7.3
		2	51.7	45.9	6.1
		3	53.9	45.3	8.8
		3	52.3	44.8	6.2
	Minimum		50.1	43.8	4.2
	Maximum		54.3	46.6	9.9
	K_{Ic} test block		52.3	45.9	5.0

*Broke outside gage length.

Supplier	Material	Tensile Properties				DAS
		Plate	UTS (ksi)	YS (ksi)	e (%)	(x 10-4 inches)
Magnesium Alloy Products	Attached coupons					
		1A	53.1	46.9	4.1	17
		1B	52.6	45.4	3.7	25
		2A	52.5	45.2	6.2	10
		2B	53.0	46.8	3.3	21
		3A	52.6	44.5	6.0	14
		3B	52.1	44.8	4.3	16
Teledyne Cast Products	Attached coupons					
		1A	52.0	44.3	10.8	9
		1B	46.8	41.7	3.7	20
		2A	53.7	45.3	11.6	10
		2B	46.5	44.4	3.0	20
		3A	52.1	43.2	10.8	7
		3B	46.4	41.9	2.8	20

(2) Radiographic Inspection

The designated area of the step plates and the fracture toughness blocks met the Grade B quality criteria of MIL-C-6021. The remaining undesignated areas of the step plates varied between Grade B and Grade C qualities.

(3) Penetrant Inspection

No linear indications were evident in any of the qualification castings from either Magnesium Alloy Products or Teledyne Cast Products.

(4) Hardness Test

The step plates varied in hardness from HRE 90 to 97. The hardness determinations were obtained for information only to properly characterize heat treated A357 alloy in the T6 condition.

(5) Melt Composition

The following compositions were reported by the two foundries:

Element	Magnesium Alloy Products (Content %)	Teledyne Cast Products (Content %)
Silicon	6.70	7.00
Magnesium	0.59	0.60
Iron	0.11	0.09
Titanium	0.14	0.13
Beryllium	0.06	0.05
Manganese	0.10	Nil
Zinc	0.01	0.01
Copper	0.01	0.01
Aluminum	Remainder	Remainder

(6) Summary and Conclusions

Magnesium Alloy Products and Teledyne Cast Products demonstrated that their processes were capable of producing A357-T6 material that would meet (1) target properties of 50 ksi UTS, 40 ksi YS, and 5-percent elongation in the fracture toughness blocks and designated area of the step plate, (2) Grade C or better radiographic quality in the undesignated areas of the step plates, (3) melt composition requirements with restricted magnesium content, (4) acceptable surface quality, and (5) DAS requirements of attached coupons, with the exception that those produced by Magnesium Alloy Products did not show an acceptable variance in the DAS value of the attached coupons. Approval was given to both foundries, with the condition that Magnesium Alloy Products would develop an acceptable method of producing attached coupons to the step plates that would show a minimum of a 0.0010-inch spread in DAS values.

c. Test Results, A201 Alloy

(1) Tensile Properties

A201-T7 Step Plates and Fracture Toughness Blocks exhibited the following tensile properties:

Supplier	Material	Tensile Properties of Specimens Excised from the Designated Area			
		Plate	UTS (ksi)	YS (ksi)	e (%)
Smithford Products Co.	Step plates				
		1	62.1	56.1	14.0
		1	61.2	55.1	10.0
		1	68.4	62.5	8.2
		1	69.0	62.7	7.0
		1	68.6	62.2	7.2
		2	60.4	54.2	14.0
		2	66.3	59.8	8.5
		2	60.5	54.2	10.0
		2	67.9	62.1	5.0
		3	61.5	55.2	10.0
		3	66.2	59.5	7.4
		3	60.2	53.5	12.0
		3	68.6	62.1	7.5
	Minimum		60.2	54.2	5.0
	Maximum		69.0	62.7	14.0

Supplier	Material	Tensile Properties of Specimens Excised from the Designated Area			
Morris Bean and Company	Step plates	Plate	UTS (ksi)	YS (ksi)	e (%)
		1	63.9	57.2	6.4
		1	65.7	58.4	9.1
		1	63.2	56.4	7.8
		2	65.0	58.1	5.1
		2	67.0	59.2	9.2
		2	63.0	56.4	6.5
		3	65.5	58.1	7.4
		3	64.4	57.3	9.3
		3	66.5	59.4	8.4
		3	65.5	58.4	10.3
		3	64.4	57.3	8.8
		3	64.4	57.6	7.2
	Minimum		63.0	56.4	5.1
	Maximum		67.0	59.4	10.3

Supplier	Material	Tensile Properties of Specimens Excised from the Designated Area			
		Plate	UTS (ksi)	YS (ksi)	e (%)
Smithford Products Co.	Fracture toughness blocks		68.8	59.9	5.0
Morris Bean and Company	Fracture toughness block		64.9	59.1	6.5
Smithford Products Co.	Attached coupons	1	62.3	58.0	10.0
		2	63.8	58.2	9.0
		3	61.0	55.7	8.0
Morris Bean and Company	Attached coupons	1	65.6	57.8	9.6
		2	65.0	57.0	8.9
		3	65.7	58.0	10.8

(2) Radiographic Inspection

Smithford step plates were classified Grade B in the designated area. Non-designated areas exhibited round gas porosity and scattered amounts of shrink sponge and shrink cavities in the remaining areas of the casting which were of Grade C quality. All areas of the Morris Bean step plates were classified Grade B or better although there were indications of dross and gas holes.

(3) Penetrant Inspection

All step plates were acceptable.

(4) Melt Composition

The following melt compositions were reported by the foundries:

Element	Smithford Products Co. (Content %)	Morris Bean and Company (Content %)
Copper	4.75	4.68
Silicon	0.04	0.02
Magnesium	0.29	0.29
Iron	0.03	0.03
Manganese	0.29	0.29
Titanium	0.28	0.20
Silver	0.51	0.51

(5) Hardness Tests

The following hardness test results were reported by the foundries:

Foundry	Plate	HRB
Smithford Products Co.	1	76.5
	2	72.0
	3	75.0
Morris Bean and Company	1	78.6
	2	75.0
	3	76.0

(6) Electrical Conductivity

The following electrical conductivity test results were obtained:

Foundry	Plate	IACS (%)
Smithford Products Co.	1	32.0
	2	31.5
	3	31.0
Morris Bean and Company	1	31.4
	2	31.5
	3	31.0

(7) Summary and Conclusions

Smithford Products Company and Morris Bean and Company each demonstrated capability to produce step plates and fracture toughness castings to the desired quality. Both foundries were approved for production on the basis of these results. It should be noted that although both foundries had produced premium quality castings for aerospace applications for a number of years, several trial efforts were necessary before castings were made which met the requirements for process approval.

3. PRODUCTION ACCEPTANCE TESTING

a. Introduction

After qualification approval each foundry was requested to cast 15 step plates and 5 fracture toughness blocks. The castings were to be produced from a minimum of five melts and two heat treatment lots at each foundry. In addition, each foundry was requested to produce three step plates with radiographic quality worse than Grade C per MIL-C-6021 in the designated area and three additional plates each with a weld bead across the designated area in a 60-degree groove 0.25 inch deep.

The test castings were to be produced in accordance with the production control procedures used in the production of the qualification plates and the acceptance criteria described herein. Discussions were held with the participating foundries to clarify acceptance criteria. The NDI criteria were based on the acceptance test procedures defined in Phase IA and the results of the qualification tests.

b. Acceptance Criteria

(1) A357-T6 test castings

The following inspection test methods and criteria of acceptance were developed for A357-T6 castings:

Test Method	Acceptance Criteria
Radiographic inspection per MIL-STD-00453 (1% t, 0.003 inch UG, Type 1 film)	Grade B per MIL-C-6021 minimum in designated area; Grade C minimum all other areas
Flourescent penetrant per AMS 2645	No linear indications
Tensile test attached coupon per ASTM B557	Minimum of 50 ksi UTS, 42 to 47 ksi YS
DAS measurement by proposed AMS method	Maximum size determined by UTS/DAS relationship of attached coupons for 50 ksi UTS

In addition, each foundry was to supply a spectrographic analysis of each melt, heat treatment certifications, and individual cast serial numbers on each step plate. The melt chemistry was to be in accordance with MIL-A-21180 except that the magnesium content was to be maintained within a range of 0.55 to 0.65 percent instead of the specified range of 0.40 to 0.7 percent. The acceptance criteria for the fracture toughness blocks

were the same as for the step plates, except that the radiographic quality could not be validated because of the thickness of the block.

(2) A201-T7 Test Castings

The following test methods and criteria of acceptance for A201-T7 were developed:

Test Method	Acceptance Criteria
Radiographic inspection per MIL-STD-00453 (1% t, 0.003 inch Ug, Type 1 film)	Grade B per MIL-C-6021 in designated area; Grade C in all other areas
Fluorescent penetrant per AMS 2645	No linear indications
Tensile test attached coupon	Minimum of: 60 ksi UTS 55 ksi YS 5% elongation
Hardness per ASTM E18	Minimum of HRB 70
Electrical conductivity per MIL-STD-1537	Minimum of 31% IACS

In addition, each foundry was requested to supply a spectrographic analysis of each melt, heat treatment certifications, and individual cast serial numbers on each plate. The melt composition was to be in accordance with specification MIL-A-21180, except for the following:

Copper	4.5 to 5.0%
Silver	0.5 to 1.0%
Magnesium	0.25 to 0.35%

c. A357-T6 Test Results

(1) Teledyne Cast Products Test Castings

Melt Chemistry - As shown in Table 9, the five melts all met the composition acceptance limits. The magnesium content was maintained in

the upper portion of the composition range and the iron was consistently in the lower portion of the composition range.

TABLE 9. TELEDYNE CAST PRODUCTS COMPANY (A357) FOUNDRY MELT ANALYSIS

Element	Acceptance Limits (%)	Melt 4913	4203	4213	4223	9193
Silicon	6.50 to 7.50	6.80	6.80	6.80	6.80	6.60
Magnesium	0.55 to 0.65	0.59	0.60	0.59	0.60	0.64
Titanium	0.10 to 0.20	0.17	0.15	0.16	0.15	0.12
Beryllium	0.04 to 0.07	0.06	0.06	0.07	0.07	0.06
Iron	0.20 Max	0.06	0.06	0.08	0.06	0.07
Manganese	0.35 Max	-	-	-	-	-
Zinc	0.05 Max	0.01	0.01	0.01	0.01	-
Copper	0.05 Max	0.03	0.03	0.01	0.01	-
Aluminum	Remainder			Remainder		

Radiographic Quality - The 15 cast step plates were acceptable to Grade B quality requirements in both designated and nondesignated areas. Details of the results are shown in Table 10.

Integrally Attached Coupon Tensile Properties - The tensile property results shown in Table 11 of chilled and unchilled attached coupon met the yield strength range of 42 to 47 ksi in the chilled coupons. A minimum of 50 ksi ultimate strength was also obtained in each of the chilled coupons. Values varied from 52.2 to 54.7 ksi UTS.

DAS - Measurements of DAS taken on the surface of chilled and unchilled attached coupons of the 15 cast step plates are reported in Table 12 with the UTS of each coupon. These results were also plotted in Figure 86 to determine the maximum DAS value which could be allowed and ensure a 50 ksi UTS (as listed in Table 12). Using the maximum DAS value determined from the attached coupons as a reference, two test sites of the designated area were inspected to determine the acceptance of each plate. The DAS value of each plate of plates varied from 9 to 19 x 10^{-4} inches which was acceptable to the respective maximum allowable DAS value of each plate. The DAS values obtained from each plate is shown in Table 12.

TABLE 10. TELEDYNE CAST PRODUCTS COMPANY (A357) PRODUCTION STEP PLATES RADIOGRAPHIC INSPECTION RESULTS

PLATE	RADIOGRAPHIC QUALITY			
	DESIGNATED AREA (1)		NON-DESIGNATED AREA (2)	
	ASTM PLATE NO.	TYPE DEFECT	ASTM PLATE NO.	TYPE DEFECT
4193-1	<1	Rd Gas Por	1 to <1	Rd Gas Por
			1	Gas Hole
-2	<1	Rd Gas Por	<1	Rd Gas Por
			<1	Gas Hole Dross
-4	<1	Rd Gas Por	1 to <1	Rd Gas Por
			1	Gas Hole Dross
-5	<1	Rd Gas Por	<1	Rd Gas Por
			<1	Gas Hole
4203-1	<1	Rd Gas Por	<1	Rd Gas Por
-3	<1	Gas Hole	1 to <1	Rd Gas Por
			<1	Gas Hole
-4		None	<1	Rd Gas Por
			<1	Gas Hole
4213-1	<1	Rd Gas Por	1	Rd Gas Por
	<1	Gas Hole	<1	Gas Hole
-4	<1	Rd Gas Por	<1	Rd Gas Por
			<1	Gas Hole
4223-2	1	Rd Gas Por	1	Rd Gas Por
	1	Spng. Shrink		
-5	1	Rd Gas Por	<1	Rd Gas Por
	1	Spng. Shrink	1 to <1	Gas Hole
9193-1	<1	Rd Gas Por	<1	Rd Gas Por
-2	<1	Rd Gas Por	<1	Rd Gas Por
-4	<1	Rd Gas Por	<1	Rd Gas Por
			<1	Gas Hole
-8	<1	Rd Gas Por	<1	Rd Gas Por
	1	Spng. Shrink	<1	Gas Hole

(1) Grade B quality required. Maximum defect not to exceed a Plate 1.

(2) Grade C quality required. Maximum defect not to exceed a Plate 2 except gas porosity or gas hole defect cannot exceed Plate 3.

TABLE 11. TELEDYNE CAST PRODUCTS COMPANY (A357) INTEGRALLY ATTACHED TEST COUPON PROPERTIES

Coupon 1 - Chilled
Coupon 2 - No Chill

Plate No.	Test Coupon	UTS (ksi)	YS (ksi)	e (%)
4193-1	1	52.8	42.1	10.0
	2	47.4	41.2	2.0
-3	1	54.1	44.6	10.0
	2	48.0	43.0	2.5
-4	1	53.6	42.9	11.0
	2	49.1	43.2	3.0
-5	1	52.2	42.0	10.0
	2	48.5	42.0	4.0
4203-1	1	54.1	42.9	10.0
	2	49.5	44.5	2.0
-3	1	54.0	44.0	10.0
	2	48.1	43.0	2.5
-4	1	53.9	44.2	8.0
	2	48.9	43.4	2.5
4213-1	1	54.0	44.1	12.0
	2	49.0	44.0	2.5
-4	1	54.5	44.2	11.0
	2	48.5	43.9	2.0
4223-2	1	53.5	44.0	10.0
	2	49.9	44.3	3.0
-5	1	53.6	44.1	9.0
	2	49.6	44.3	4.0
9193-1	1	53.4	44.0	10.0
	2	49.6	42.6	4.0
-2	1	54.2	44.8	10.0
	2	49.6	43.0	3.0
-4	1	54.7	45.2	12.0
	2	50.8	44.4	5.0
-8	1	53.2	43.3	12.0
	2	50.5	44.2	5.0

TABLE 12. TELEDYNE CAST PRODUCTS COMPANY (A357) PRODUCTION STEP PLATE DAS ACCEPTANCE TEST RESULTS

Plate No.	DAS/UTS (10^{-4} inch/ksi) Chilled Coupon	DAS/UTS (10^{-4} inch/ksi) Unchilled Coupon	DAS At Center Casting	DAS At Edge Casting	Graph Maximum Allowable DAS (10^{-4} in)
4193-1	*(15) 1/52.8	*(36) 24/47.4	9	13	18 (26)*
-3	*(16) 11/54.1	*(40) 22/48.0	9	16	18 (32)*
-4	9/53.6	23/49.1	9	17	20
-5	10/52.2	22/48.5	11	16	17
4203-1	*(20) 11/54.1	*(38) 24/49.5	8	16	22 (36)*
-3	*(15) 9/54.0	*(35) 25/48.1	9	14	20 (29)*
-4	12/53.9	25/48.9	11	17	22
4213-1	*(16) 11/54.0	*(33) 24/49.0	9	14	21 (29)*
-4	*(17) 12/54.5	*(32) 21/48.5	8	14	17 (28)*
4223-2	10/53.5	20/49.9	8	17	20
-5	*(15) 9/53.6	*(36) 22/49.6	9	17	21 (35)*
9193-1	*(14) 8/53.4	*(22) 20/49.6	11	15	19 (21)*
-2	*(13) 8/54.2	*(29) 22/49.6	9	19	21 (27)*
-4	*(15) 8/54.7	*(30) 19/50.8	10	12	21 (32)+
-8	9/53.2	20/50.5	9	13	22

*(XX) Represents the "partilce intercept distance" (X10^{-4} inches) and is shown with DAS values. This comparison is discussed in the following text of the report.

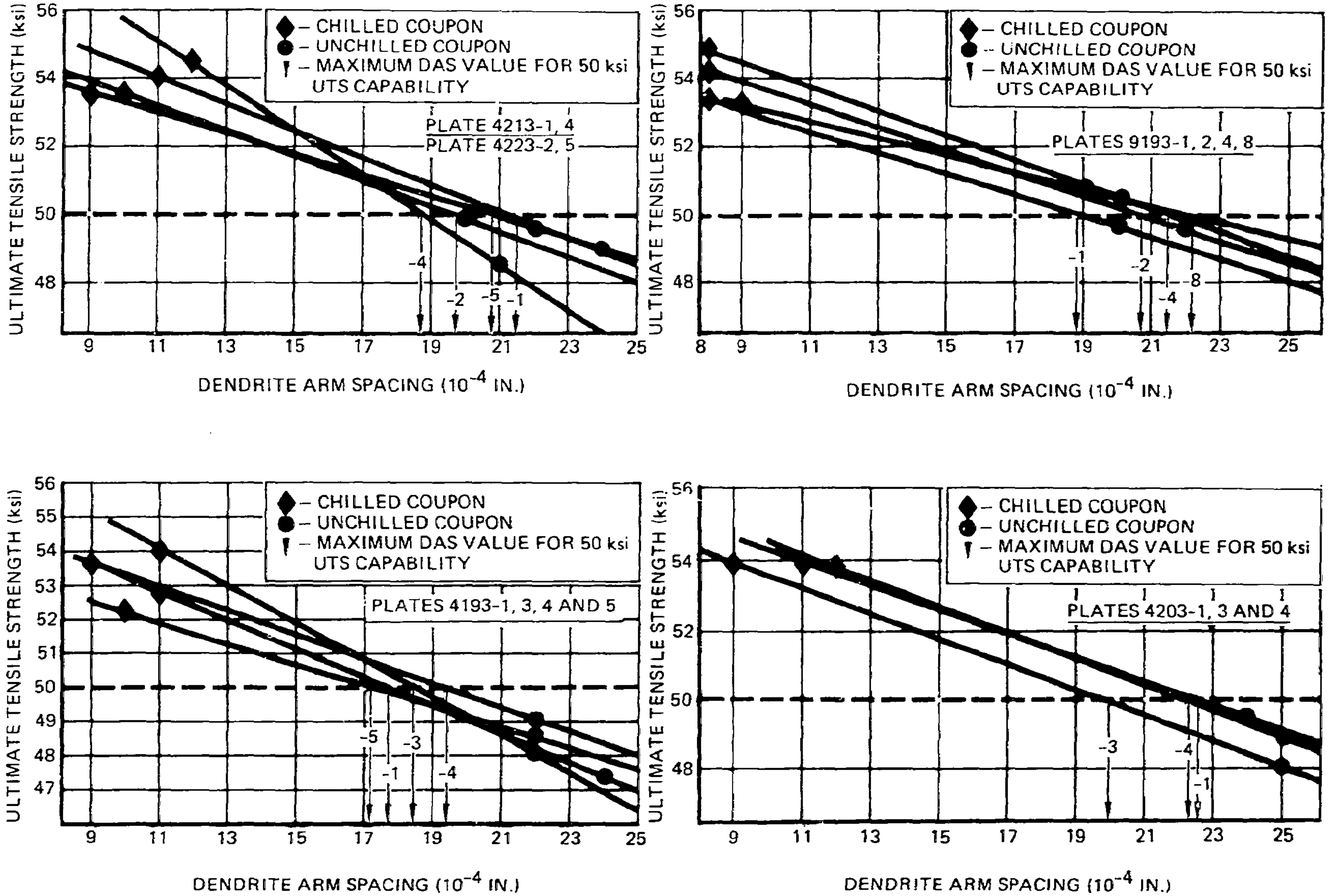


FIGURE 86. GRAPHIC DETERMINATION OF MAXIMUM PLATE DAS VALUE OF TELEDYNE CAST PRODUCTS STEP PLATES FROM DAS AND UTS VALUES OF ATTACHED COUPONS

To verify the microstructure acceptance procedure, the microstructure was evaluated by two methods. The preferred procedure was to locate well-defined dendritic formations and carefully determine the DAS of several dendrites and use the average value. However, in some instances, the dendritic formation was not clearly defined. In these instances, lines were arbitrarily drawn across the micrograph and the average distance between the silicon particles that intercepted the line was determined. This distance has been defined as the average particle intercept distance (PID). Both procedures are described in the proposed process specification (Appendix H). The microstructure of the attached coupons and several step plates was measured by both methods (results are plotted in Figures 87 and 88). The UTS was then predicted by each method and a tensile specimen excised from the test site. This was done to compare the two methods of microstructure measurement. The results are shown in Table 13. The predicted value of UTS as determined by using PID and DAS measurements were very similar. A tolerance of $\pm$ 5 percent or 2.5 ksi was anticipated and the results were within this range of variation. It should be noted however, that the accuracy of the PID method is reduced with increasing amounts of interdendritic material. For this reason, the accuracy of measuring coarse structures which exhibit large amounts of interdendritic material is limited using the PID method.

Hardness and Penetrant Inspection - Penetrant inspection indicated no linear defects and the results were acceptable as shown in Table 14. Hardness values were reported for information purposes only and are shown also in Table 14. The values varied from 95.1 to 100.2 HRE.

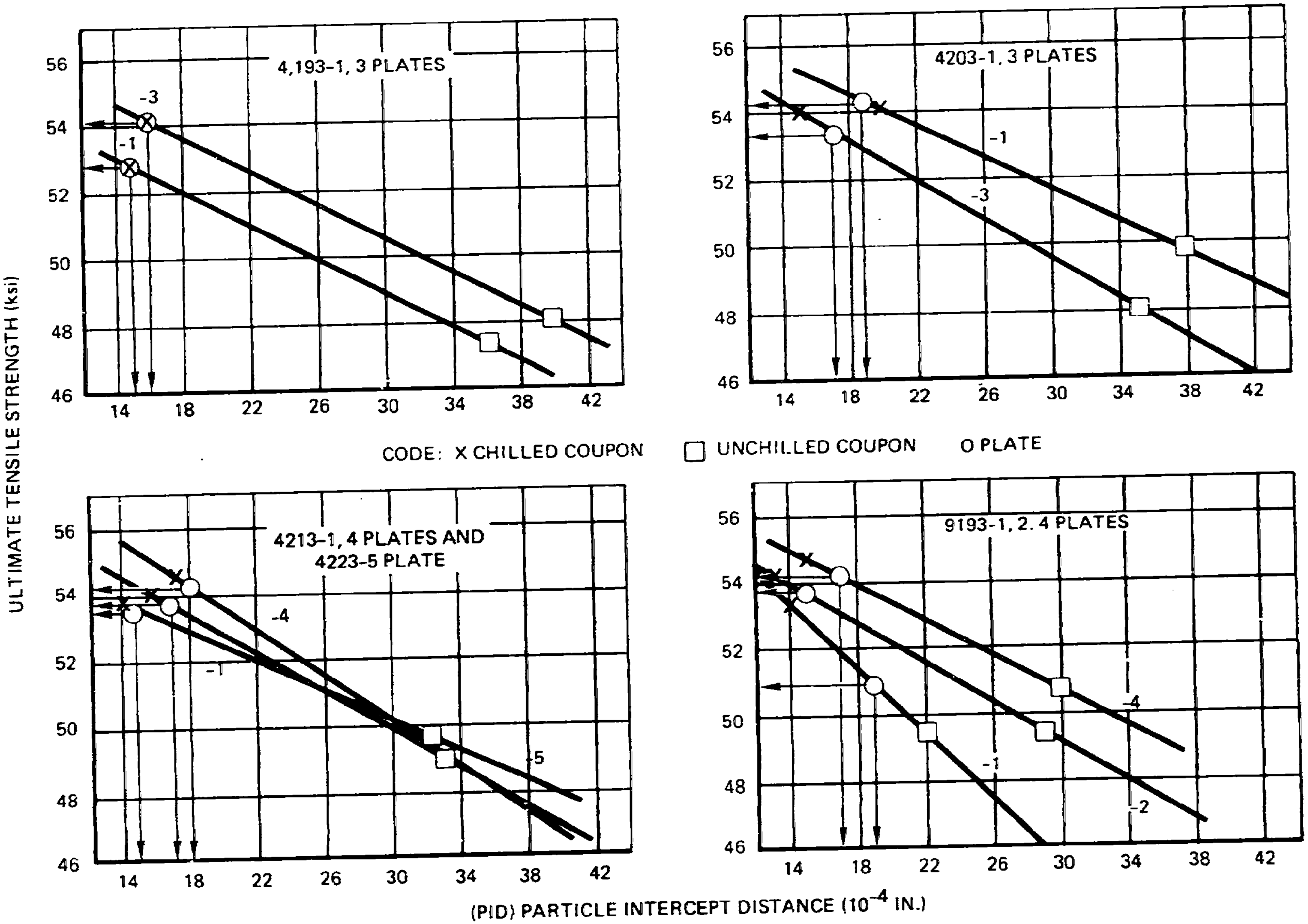


FIGURE 87. GRAPHIC DETERMINATION OF PLATE UTS DETERMINED FROM PID OF TELEDYNE CAST PRODUCTS STEP PLATES AND PID/UTS VALUES OF ATTACHED COUPONS

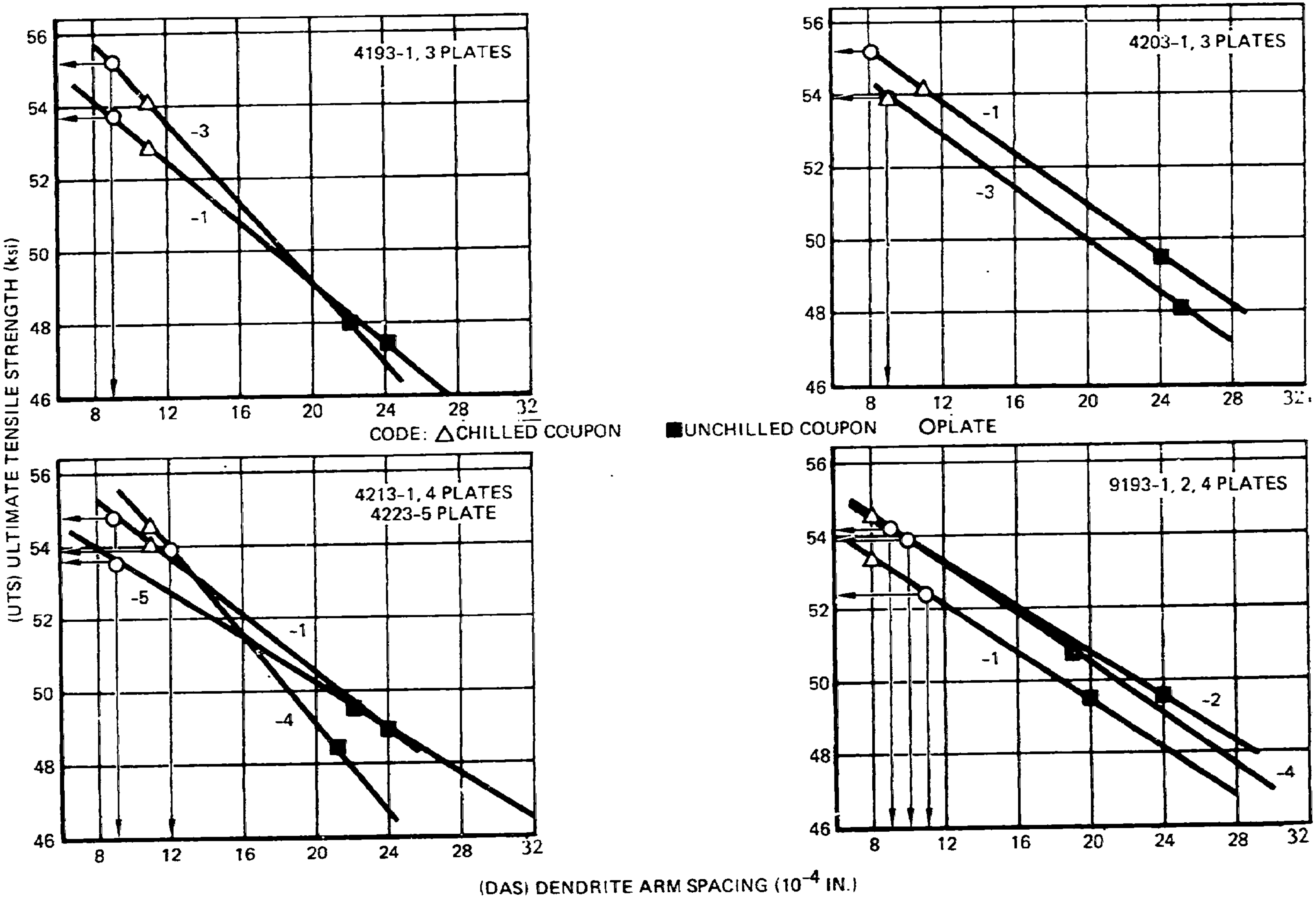


FIGURE 88. GRAPHIC DETERMINATION OF PLATE UTS DETERMINED FROM DAS OF TELEDYNE CAST PRODUCTS STEP PLATES AND DAS/UTS VALUES OF ATTACHED COUPONS

TABLE 13. COMPARISON OF TENSILE STRENGTH ESTIMATION USING DAS AND PID MEASUREMENTS OF TELEDYNE CAST PRODUCTS (A357) STEP PLATES

Plate No.	Tensile Specimen	Microstructure Measurement by		Tested UTS (ksi)	Estimated UTS by		Difference of Estimated and Tested	
		PID (10^{-4} inch)	DAS (10^{-4} inch)		PID (ksi)	DAS (ksi)	PID (ksi)	DAS (ksi)
9193-1	A86-T3	19	11	52.5	51.0	52.4	-1.5	-0.1
9193-2	B85-T3	15	9	52.8	53.6	54.2	+0.8	+1.4
9193-4	B90-T3	17	10	52.8	54.2	54.0	+1.4	+1.2
4213-1	B92-T3	17	9	54.7	53.7	54.8	-1.0	+0.1
4213-4	A91-T3	18	12	51.9	54.1	53.9	+2.2	+2.0
4203-1	A95-T3	19	8	54.2	54.4	55.2	+0.2	+1.0
4203-3	B94-T3	17	9	53.1	53.5	54.0	+0.4	+0.9
4193-1	A99-T3	15	9	53.9	52.8	53.6	-1.1	-0.3
4193-3	B98-T3	16	9	52.7	54.1	55.2	+1.4	+2.5
4223-5	A87-T3	15	9	54.0	53.4	53.6	-0.6	-0.4

TABLE 14. TELEDYNE CAST PRODUCTS (A357) STEP PLATE PENETRANT AND HARDNESS RESULTS

Plate No.	Penetrant	Hardness (R_E)
4193-1	OK	98 to 99
-3	OK	98 to 99
-4	OK	97 to 99
-5	OK	97 to 99
4203-1	OK	99 to 100
-3	OK	97 to 99
-4	OK	97 to 98
4213-1	OK	98 to 99
-4	OK	97 to 98
4223-2	OK	97 to 100
-5	OK	95 to 99
9193-1	OK	98 to 100
-2	OK	99 to 100
-4	OK	98 to 100
-8	OK	98 to 100

(2) Magnesium Alloy Products test casting results

Melt Chemistry - Six different melts were used to pour the test castings. The melt compositions as reported by the foundry indicated a magnesium content in the lower half portion of the range and iron content in the upper half of the acceptance range. All melt compositions were within the specified acceptance range as reported in Table 15.

Radiographic Quality - The radiographic quality of the step plates was acceptable with the exception of two plates which exhibited a localized flaw. The flaws were accepted since they did not interfere with the testing. The nondesignated areas showed evidence of Grade B to C round gas porosity in the 1/8-inch thick section of the plates. All other areas met Grade B radiographic quality requirements as shown in Table 16.

TABLE 15. MAGNESIUM ALLOY PRODUCTS (A357) FOUNDRY PRODUCTION MELT ANALYSIS

Element	Acceptance Limits (%)	Melt					
		H2237/3	H2204/2	H2250/4	H2258/4	H2256/4	H2301/3
Silicon	6.5 to 7.5	6.9	6.8	6.8	7.0	6.9	6.8
Magnesium	0.55 to 0.65	0.60	0.60	0.60	0.60	0.58	0.57
Titanium	0.10 to 0.20	0.16	0.19	0.17	0.17	0.16	0.18
Beryllium	0.04 to 0.07	0.05	0.05	0.05	0.05	0.05	0.05
Iron	0.20 Max	0.13	0.15	0.12	0.13	0.14	0.15
Manganese	0.35 Max	0.10	0.10	0.10	0.10	0.10	0.10
Zinc	0.05 Max	0.01	0.01	0.01	0.01	0.01	0.01
Copper	0.05 Max	0.02	0.02	0.02	0.02	0.02	0.02
Aluminum	Remainder	Remainder					

TABLE 16. MAGNESIUM ALLOY PRODUCTS (A357) PRODUCTION STEP PLATES RADIOGRAPHIC INSPECTION RESULTS

PLATE	RADIOGRAPHIC QUALITY			
	DESIGNATED AREA (1)		NON-DESIGNATED AREA (2)	
	ASTM PLATE NO.	TYPE DEFECT	ASTM PLATE NO.	TYPE DEFECT
2237/3-13	2	Rd Gas Por	1 1	Rd Gas Por Elong Gas Por
2237/3-14	1	Rd Gas Por	1	Rd Gas Por Elong Gas Por
2237/3-15		None	1 and 2	Rd Gas Por
2244/2-17	1	Rd Gas Por	1 and 3	Rd Gas Por
2244/2-18		None	1 and 2	Rd Gas Por
2244/2-19	1	Rd Gas Por	1 and 2	Rd Gas Por
2250/4-21	1	Rd Gas Por	1 and 2	Rd Gas Por
2250/4-22	1	Rd Gas Por	1 *6	Rd Gas Por Elong Gas Por
2250/4-24	1	Rd Gas Por	1 3	Rd Gas Por Elong Gas Por
2258/4-34	1	Rd Gas Por	1	Rd Gas Por
2258/4-35	1	Rd Gas Por	1 and 2	Rd Gas Por
2258/4-36	1	Rd Gas Por	1 and 2	Rd Gas Por
2256/4-29	1	Rd Gas Por	1 and 2	Rd Gas Por
2256/4-30	1	Rd Gas Por	1	Rd Gas Por
2256/4-31	1	Rd Gas Por	1 and 2	Rd Gas Por

(1) Grade B quality required. Maximum defect was not to exceed ASTM Plate 1.

(2) Grade C quality required. Maximum defect was not to exceed ASTM Plate 2 except gas porosity and gas holes could not exceed ASTM Plate 3.

*Accepted in a localized area which does not interfere with testing

Integrally Attached Coupon Tensile Properties - The yield strength range of 42 to 47 ksi and minimum ultimate strength of 50 ksi were obtained as shown in Table 17 for each chilled attached coupon. The UTS varied from 52.5 to 55.9 ksi.

DAS - The DAS was determined on the surface of each attached coupon prior to excising a tensile specimen. The DAS/UTS relationships plotted in Figure 88 were used to determine the maximum DAS permissible for a UTS of 50 ksi. By relating the maximum DAS (as listed in Table 18) acceptable to the DAS of each plate, the capability of plate to exhibit the minimum UTS of 50 ksi required for acceptance was determined. The relatively high UTS values obtained from coarse unchilled attached coupons from plates 18, 22, and 36 provided an unusually large maximum acceptable DAS of 50, 45 and 45 x 10^{-4} inches. The microstructures of these tensile specimens were also evaluated using a mounted and polished micro preparation technique. Reexamination of the specimen microstructure did not significantly alter the DAS/UTS relation originally established. However, the tensile properties of a specimen taken adjacent to the coarse DAS coupon of plate 36 indicated a much lower value of UTS. As shown in Figure 89, when the lower UTS was used in place of the original UTS value, the DAS/UTS relationship paralleled the results of the other two plates of the same melt. The apparent discrepancies of the DAS/UTS relationship of plates 18, 22 and 36 were attributed to the inaccuracy of the UTS values.

Hardness and Penetrant Inspection - The hardness values of the plates were found to vary from HRE 95.0 to 101.5. Penetrant inspection showed no evidence of linear indications. Results of these tests are shown in Table 19.

TABLE 17. MAGNESIUM ALLOY PRODUCTS (A357) INTEGRALLY ATTACHED TEST COUPONS TENSILE PROPERTIES

Coupon 1 - Chilled
Coupon 2 - Not Chilled

Plate Identification	Coupon	Tensile Properties UTS (ksi)	YS (ksi)	e (%)
2237/3-13	1	53.1	45.5	9
	2	48.6	43.5	5
3-14	1	54.8	44.9	10
	2	51.9	45.9	10
3-15	1	52.5	44.6	10
	2	51.2	45.2	5
2244/2-17	1	52.5	47.3	6
	2	46.0	42.8	5
2-18	1	52.5	44.6	6
	2	51.9	45.7	7
2-19	1	52.8	44.5	8
	2	51.5	45.2	6
2250/4-21	1	55.6	46.9	11
	2	53.2	46.5	5
4-22	1	53.3	44.9	8
	2	52.2	46.4	6
4-24	1	53.6	45.2	8
	2	51.8	45.5	6
2256/4-29	1	54.4	45.5	11
	2	49.7	44.1	4
4-30	1	54.7	45.7	7
	2	51.2	43.5	5
4-31	1	53.7	45.1	8
	2	50.2	42.4	7
2258/4-34	1	55.9	46.7	8
	2	51.0	44.4	4
4-35	1	53.2	44.7	7
	2	48.5	42.4	4
4-36	1	54.2	46.5	7
	2	52.0	45.2	5
4-36 (Adjacent Specimen)	1	55.5	46.8	10
	2	44.3	44.0	--

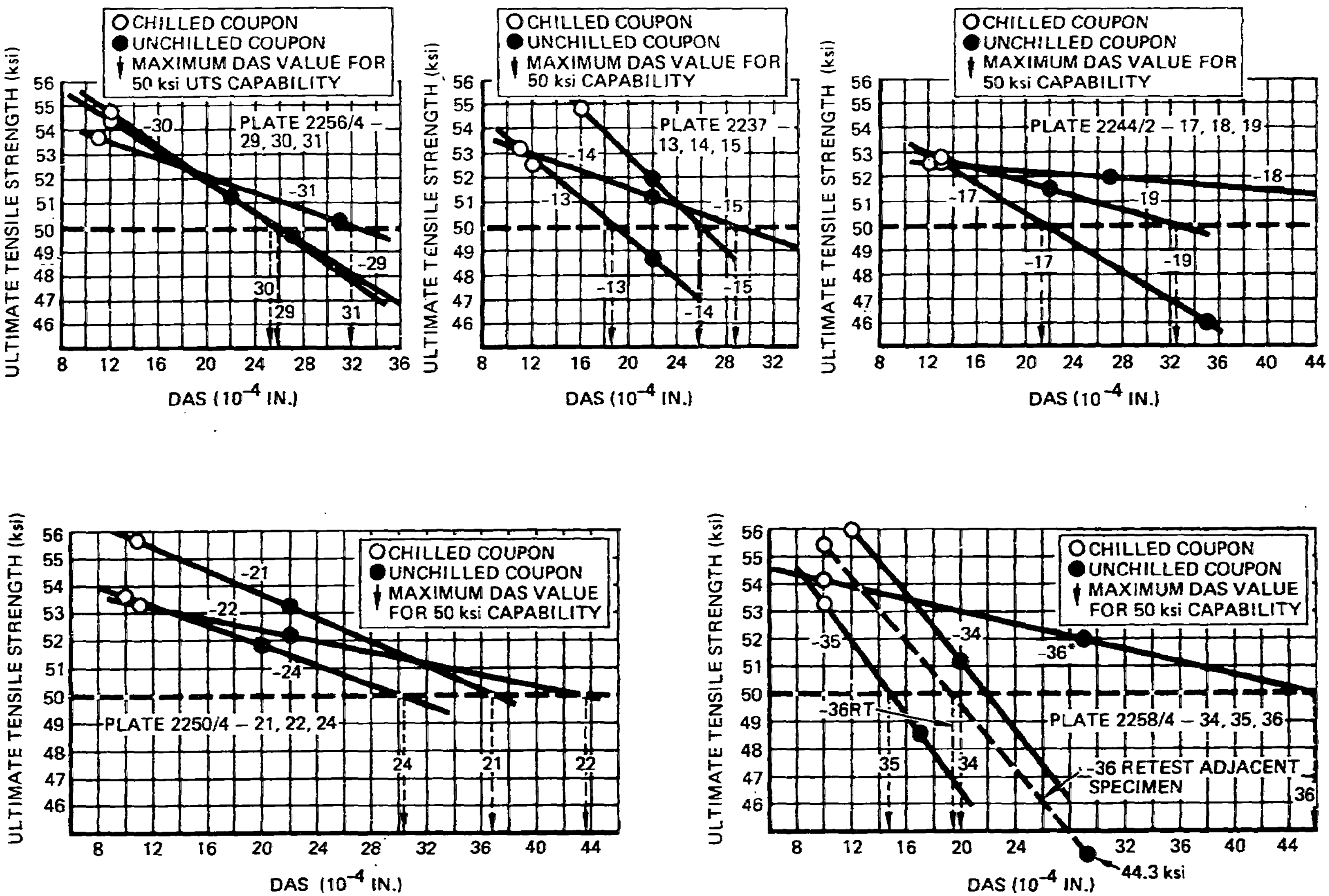


FIGURE 89. GRAPHIC DETERMINATION OF MAXIMUM DAS VALUE OF MAGNESIUM ALLOY PRODUCTS STEP PLATES DETERMINED FROM DAS AND UTS OF ATTACHED COUPONS

TABLE 18. MAGNESIUM ALLOY PRODUCTS (A357) PRODUCTION STEP PLATE DAS TEST RESULTS

Plate		Attached Coupon DAS/UTS (10^{-4} in/ksi) Chill	Non-Chill	Critical Area DAS (10^{-4} in) Center	Edge	Max. Allowable DAS (10^{-4} in) From Graph
2237/3	-13	9/53.1	20/48.6	11	16	16
	-14	14/54.8	20/51.9	10	13	24
	-15	9/52.5	20/51.2	11	17	27
2244/2	-17	11/52.5	33/46.0	12	13	19
	-18	10/52.5	25/51.9	10	17	50*
	-19	11/52.8	20/51.5	13	16	27
2250/4	-21	11/55.6	22/53.2	10	13	36
	-22	11/53.3	22/52.2	14	17	45*
	-24	10/53.6	20/51.8	14	17	29
2258/4	-34	12/55.9	20/51.0	13	13	22
	-35	10/53.2	17/48.5	11	13	14
	-36	10/54.2	29/52.0	11	17	45*
(Retest	-36	55.5	44.3			19)
2256/4	-29	10/54.4	25/49.7	10	17	24
	-30	10/54.7	20/51.2	14	20	23
	-31	9/53.7	29/50.2	13	20	28

*Suspect Results

TABLE 19. MAGNESIUM ALLOY PRODUCTS (A357) STEP PLATE HARDNESS AND PENETRANT RESULTS

Plate No.	Penetrant	Hardness (R_E)
2237/3-13	OK	98 to 99
-14	OK	98 to 101
-15	OK	97 to 99
2244/2-17	OK	95 to 97
-18	OK	97 to 98
-19	OK	97 to 99
2250/4-21	OK	99 to 102
-22	OK	98 to 100
-24	OK	97 to 100
2258/4-34	OK	99 to 102
-35	OK	97 to 100
-36	OK	97 to 100
2256/4-29	OK	99 to 101
-30	OK	98 to 100
-31	OK	97 to 98

d. A201-T7 Test Results

(1) Smithford Products Company Test Casting

Melt Composition - The composition of each melt is shown in Table 20. As these results show, the alloy content was maintained in the lower portion of the acceptance range as reported by the foundry.

Radiographic Quality - The results of radiographic inspection, shown in Table 21, indicated the step plates were acceptable to a Grade B quality in all areas of each plate.

Integrally Attached Coupon Tensile Properties - All attached coupons met the 55 ksi yield strength, 60 ksi ultimate strength, and 5 percent minimum elongation acceptance requirements. UTS values ranged from 62.0 to 66.3 ksi; YS values varied from 57.0 to 60.0 ksi and elongation values ranged from 6.4 to 9.6 percent. Test results are shown in Table 22.

Hardness and Conductivity - The hardness values of the step plates varied from 75 to 81 HRB, which was consistent with the required minimum of 70 HRB. Electrical conductivity measurements varied from 31 to 33 percent IACS in compliance with the minimum requirement of 31 percent IACS. Values of hardness and conductivity are listed in Table 22.

Penetrant Inspection - The surface quality of this alloy as determined by penetrant inspection may be very misleading due to a thin layer of metal on the surface of the casting. This skin will often contain irregularities such as tears or linear indications. When this skin was sand-blasted away, the underlying surface was free of any linear indications, as shown in Figure 90.

TABLE 20. SMITHFORD PRODUCTS (A201) FOUNDRY MELT COMPOSITION

Element of Melt	Acceptance Range (%)	Melt U429 (%)	Melt 124-A (%)	Melt 124-P (%)	Melt 214 (%)
Copper	4.50 to 5.00	4.70	4.75	4.75	4.70
Silicon	0.10 max	0.04	0.04	0.05	0.03
Magnesium	0.25 to 0.35	0.34	0.31	0.32	0.30
Iron	0.05 max	0.04	0.04	0.04	0.02
Manganese	0.20 to 0.50	0.26	0.29	0.30	0.25
Titanium	0.15 to 0.35	0.26	0.24	0.34	0.25
Silver	0.50 to 1.00	0.53	0.54	0.54	0.53

TABLE 21. RADIOGRAPHIC AND PENETRANT INSPECTION RESULTS OF SMITHFORD PRODUCTS (A201) PRODUCTION STEP PLATES

PLATE	RADIOGRAPHIC QUALITY			
	DESIGNATED AREA (1)		NON-DESIGNATED AREA (2)	
	ASTM PLATE NO.	TYPE DEFECT	ASTM PLATE NO.	TYPE DEFECT
U429-1	1	Rd Gas Por	1	Rd Gas Por
124A-2		None	1	Rd Gas Por
124P-1		None		None
U429-2		None		None
124P-2		None	1	Rd Gas Por
124A-1		None	1	Gas Hole
U429-3		None		None
124A-4		None		None
124A-3		None	1	Rd Gas Por
U429-4		None		None
124A-5		None		None
124P-4	1	Gas Hole		None
124A-3	1	Gas Hole	1	Rd Gas Por
124P-5		None	1	Rd Gas Por
214-4		None		None

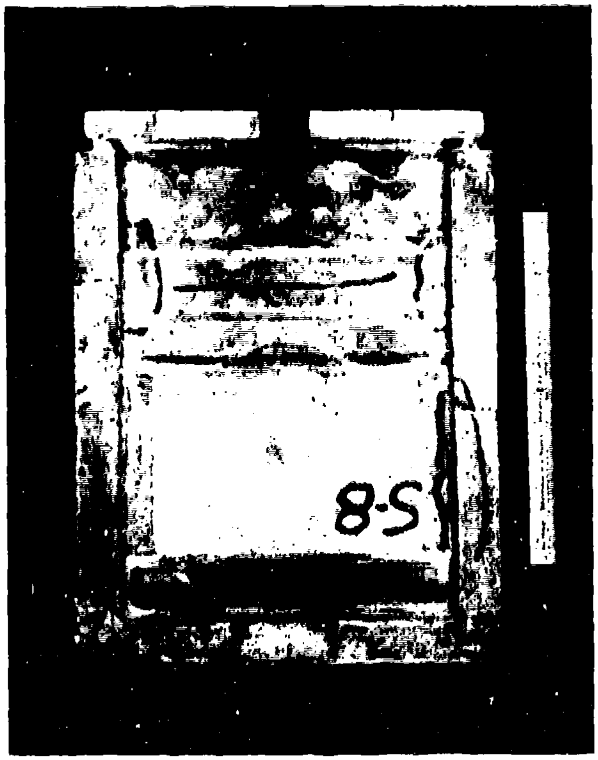
(1) Grade B quality required. Maximum defect was not to exceed ASTM Plate 1.

(2) Grade C quality required. Maximum defect was not to exceed ASTM Plate 2 except gas porosity and gas holes could not exceed ASTM Plate 3.

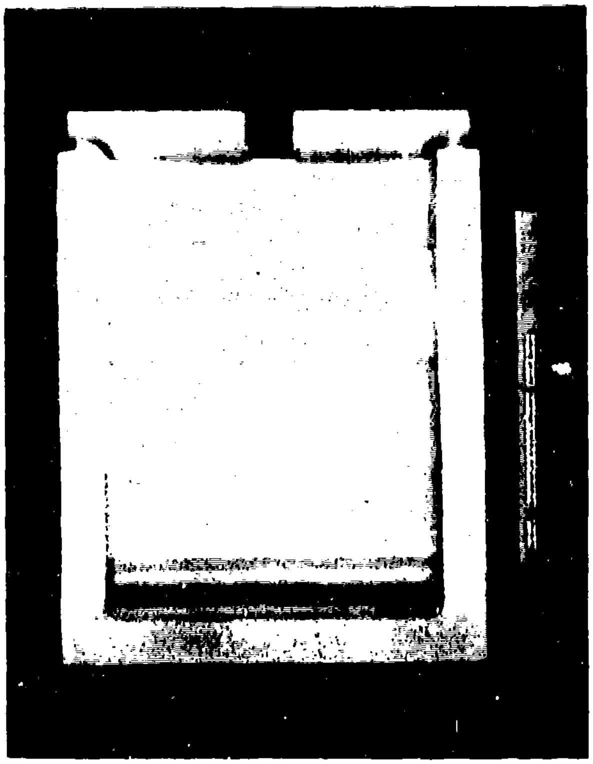
Penetrant quality of all plates was acceptable - no record kept of individual plate quality.

TABLE 22. HARDNESS AND CONDUCTIVITY TEST RESULTS OF SMITHFORD PRODUCTS (A201) STEP PLATES AND TENSILE PROPERTIES OF ATTACHED COUPONS

Test No.	Step Plate	Attached Coupon Tensile Properties UTS (ksi)	YS (ksi)	e (%)	Step Plate Hardness (HRB)	Step Plate (% IACS)
101	U429-1	64.1	58.4	9.0	78-81	31
102	124A-2	66.1	60.0	6.9	78	32
103	124P-1	65.7	58.7	9.1	79-80	31
104	U429-2	64.3	58.7	9.0	78-83	31
105	124P-2	63.7	57.0	6.7	75-77	33
106	124A-1	65.5	59.1	6.4	78-80	32
107	U429-3	63.6	58.0	8.9	79-83	32
108	124A-4	65.6	59.3	6.9	76-79	32
109	124P-3	66.3	59.1	7.9	75-77	32
110	U429-4	62.9	58.2	9.5	80-82	32
111	124A-5	65.0	59.5	8.0	78-79	33
112	124P-4	65.3	58.5	7.3	76-77	32
113	124A-3	65.0	59.5	8.0	76-79	32
114	124P-4	64.7	57.4	8.7	79-80	31
115	214-4	62.0	58.3	8.2	78-79	33

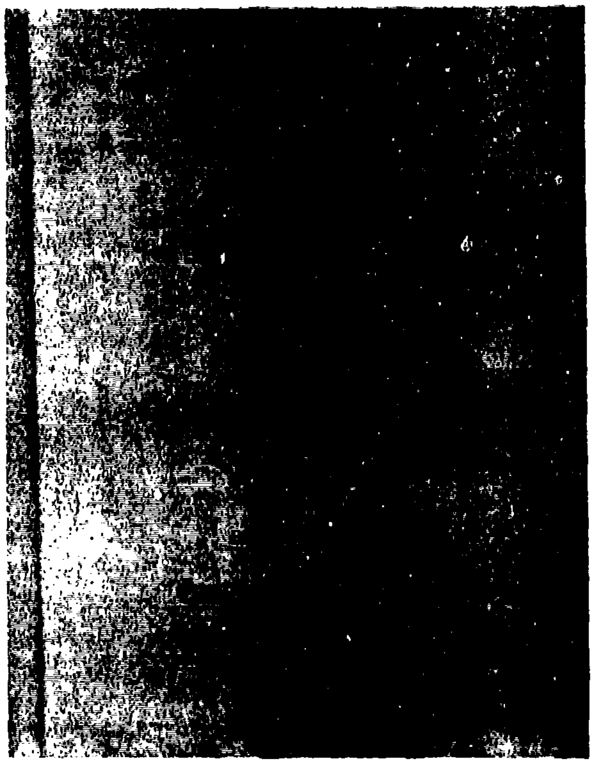


85-00238-8A
BEFORE SAND BLASTING



85-00238-8B
AFTER SAND BLASTING

85-00238-8C
BEFORE SAND BLASTING



85-00238-8D
AFTER SAND BLASTING

FIGURE 90. REMOVAL OF SURFACE INDICATIONS BY SAND BLASTING (A201 STEP PLATE)

(2) Morris Bean and Company Test Castings

Melt Composition - The foundry's spectrographic analysis of each melt is shown in Table 23. The copper content was maintained at mid-range while the magnesium content was consistently in the upper portion of the acceptable range. The silver content was kept in the lower portion of the range.

TABLE 23. MORRIS BEAN AND COMPANY (A201) FOUNDRY MELT COMPOSITIONS

Element	Acceptance Range (%)	Melt No. 1 (%)	Melt No. 2 (%)	Melt No. 3 (%)	Melt No. 4 (%)	Melt No. 5 (%)	Melt No. 6 (%)
Copper	4.50 to 5.00	4.79	4.56	4.60	4.56	4.85	4.69
Silicon	0.10 max	0.05	0.06	0.05	0.05	0.05	0.02
Magnesium	0.25 to 0.35	0.25	0.26	0.28	0.25	0.28	0.29
Iron	0.05 max	0.03	0.04	0.03	0.03	0.04	0.03
Manganese	0.20 to 0.50	0.29	0.25	0.28	0.29	0.27	0.30
Titanium	0.15 to 0.35	0.21	0.21	0.22	0.22	0.31	0.20
Silver	0.50 to 1.00	0.62	0.66	0.58	0.63	0.69	0.65

Radiographic Quality - The designated areas of all plates met Grade B quality requirements. However, the presence of dross in the non-designated areas reduced the quality from a Grade B to C. Since the minimum required quality in non-designated areas was a Grade C, the plates were acceptable. Results of the radiographic inspection are shown in Table 24.

Integrally Attached Coupons - Minimum tensile properties of 60 ksi UTS, 55 ksi YS, and 5 percent elongation were exhibited by each attached coupon as shown in Table 25. Ultimate strength values varied from 65.0 to 67.9, yield strength values varied from 57.7 to 62.5, and elongation percentage ranged from 7.8 to 9.8.

Hardness and Conductivity - Hardness and conductivity values met the minimum values of 70 HRB and 31 percent IACS respectively. Results are reported in Table 25.

Penetrant Inspection - All plates met the "no linear indication" requirement of penetrant inspection.

TABLE 24. RESULTS OF RADIOGRAPHIC AND PENETRANT INSPECTION OF MORRIS BEAN AND COMPANY (A201) PRODUCTION STEP PLATES

PLATE	RADIOGRAPHIC QUALITY			
	DESIGNATED AREA (1)		NON-DESIGNATED AREA (2)	
	ASTM PLATE NO.	TYPE DEFECT	ASTM PLATE NO.	TYPE DEFECT
29-1		None	1	Dross
-2		None		None
-3		None		None
30-1		None		None
-2		None	1	Dross
32-2		None		None
-3		None		None
33-1		None	1 and 2 2	Dross Gas Hole
34-1		None		None
-2		None		None
35-1		None	1 and 2	Dross
-2		None		None
36-1		None		None
-3		None	1	Dross
20-2		None		None

(1) Grade B quality was required. The maximum defect was not to exceed ASTM Plate 1.

(2) Grade C quality was required. The maximum defect was not to exceed ASTM Plate 2 except gas porosity and gas holes could not exceed ASTM Plate 3.

Penetrant quality of all plates was acceptable. No record was kept of individual plate quality.

TABLE 25. TENSILE PROPERTIES OF ATTACHED COUPON AND HARDNESS - CONDUCTIVITY TEST RESULTS OF (A201-T7) MORRIS BEAN AND COMPANY STEP PLATES

Step Plate Identification	Attached Coupon Tensile Properties UTS (ksi)	YS (ksi)	e (%)	Step Plate Rockwell Hardness (HRB)	Step Plate Electrical Conductivity (% IACS)
29-1	67.7	61.3	9.1	78 to 81	32
2	66.5	60.2	7.8	78 to 82	31
3	67.7	61.3	8.2	78 to 81	32
30-1	67.9	61.7	8.1	76 to 78	31
2	67.3	60.8	8.8	75 to 76	31
32-2	65.4	59.5	9.8	81 to 82	33
3	65.0	59.2	9.1	79 to 80	33
33-1	66.5	61.2	8.3	80	33
34-1	67.5	62.0	9.7	79	32
2	67.1	61.2	9.5	80 to 82	32
35-1	66.8	61.1	8.5	82	32
2	68.0	62.5	7.9	77 to 80	31
36-1	67.1	60.3	8.9	81	32
3	67.8	62.1	8.3	79 to 81	32
20-2	66.1	57.7	9.3	75 to 76	33

4. PROPERTY DETERMINATION

a. Introduction

The same procedure was used for the determination of material properties of each alloy. The testing schedule sh .n in Table 26 was performed on castings of each alloy. Specimens were excised from the step plate castings as shown in Figures 91 and 92. Design property data was determined in both designated and non-designated areas of the step plate; however, sufficient testing was done only in the designated area to analyze the results for A and B MIL-HDBK-5 properties on a statistical basis. Fracture toughness and fatigue tests were performed for comparison on both alloys using material representing three specific conditions. These were (1) acceptable quality material processed in the approved manner to represent optimum properties, (2) material that was welded to restore defective material to an acceptable NDI quality, and (3) defective material that was unacceptable because of radiographic unsoundness. The fracture toughness specimens used for comparative evaluations were all excised from a 0.5-inch thick section of the step plate. Thicker specimens were excised from separately cast test blocks in an attempt to obtain valid fracture toughness values. Crack growth specimens were prepared from step plates of both alloys and were tested by the Air Force Materials Laboratory. The test results are discussed in this report. The complete AFWAL report is included as Appendixes F and G for reference. The statistical analysis of the MIL-HDBK-5 design property data, which was performed by Battelle Columbus Laboratories, is also discussed in this section; however, the complete analytical report is included as Appendix D.

b. Test Procedure

The test procedure and specimen configurations used for the determination of each property were as follows:

1. Tensile Tests

   Tensile specimens shown in Figure 93 were excised from step plates and tested per ASTM E8, "Tension Testing of Metallic Materials". For elevated temperature tensile test, the procedure of ASTM E21 "Elevated Temperature Tensile Tests of Metallic Materials" was followed.

Table 26. TESTING SCHEDULE FOR STEP PLATE CASTINGS OF EACH ALLOY

Type Of Test	Quantity Of Specimens To Be Tested From Each Area			
	Designated Area	Non-designated Area	Welded Area	Defective Area
Tensile (Ftu, Fty, e)	100	50	10	10
Compression (Cy)	10	10		
Shear (Su)	10	10		
Bearing (1.5 e/D)				
(Fbry, Fbru)	10	10		
Bearing (2.0 e/D)				
(Fbry, Fbru)	10	10		
Tens. Elev. Temp.	20			
(250, 300, 350, 400F)				
Notched Fatigue	20		10	10
Crack Growth	5			
*Fracture Toughness (K_Q)	6		5	5

(*Thicker specimens were seperately cast to obtain K_{IC} values - 5 specimens of each alloy were tested)

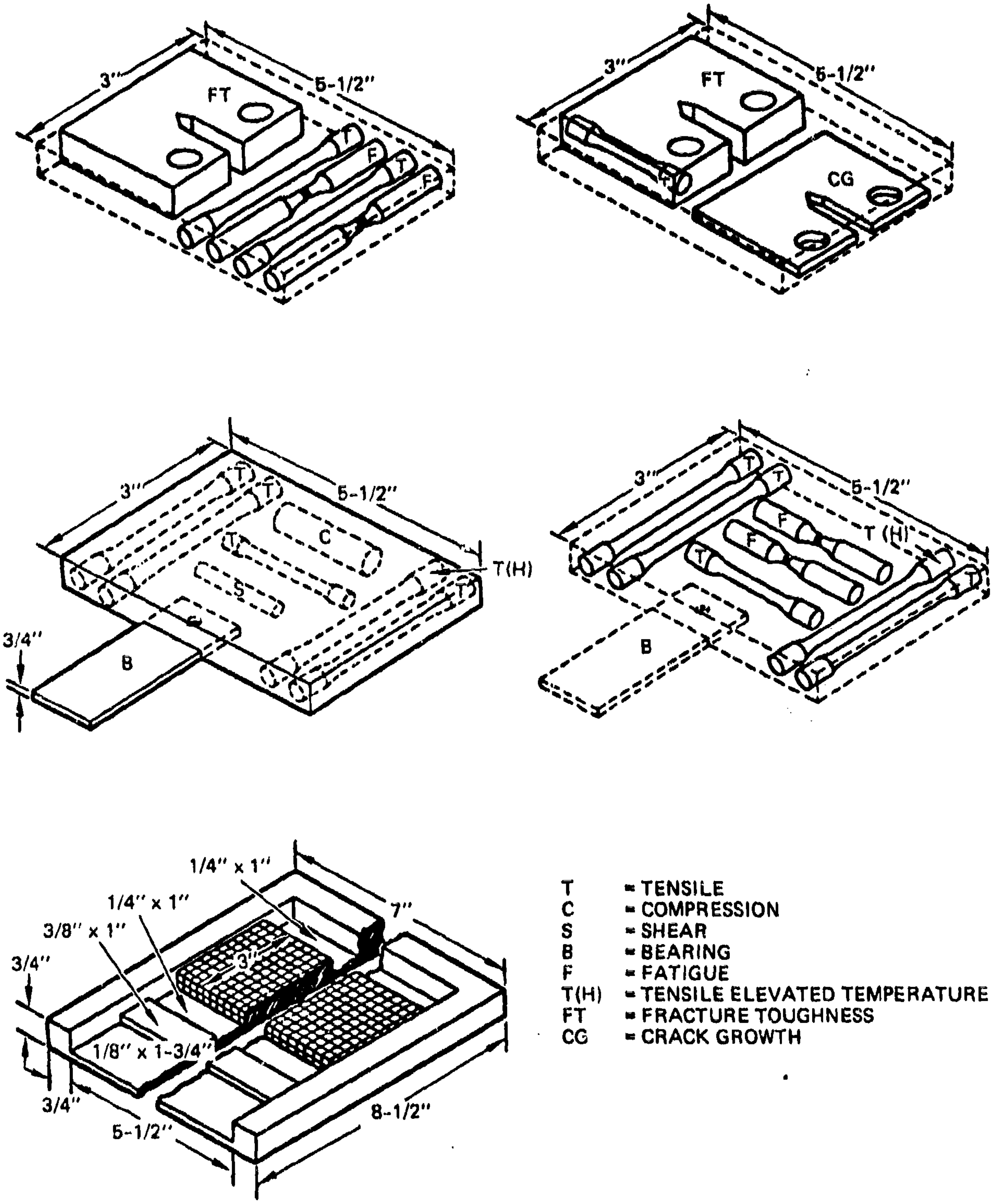


FIGURE 91. TEST SPECIMEN LOCATIONS WITHIN THE DESIGNATED AREA OF THE STEP PLATE

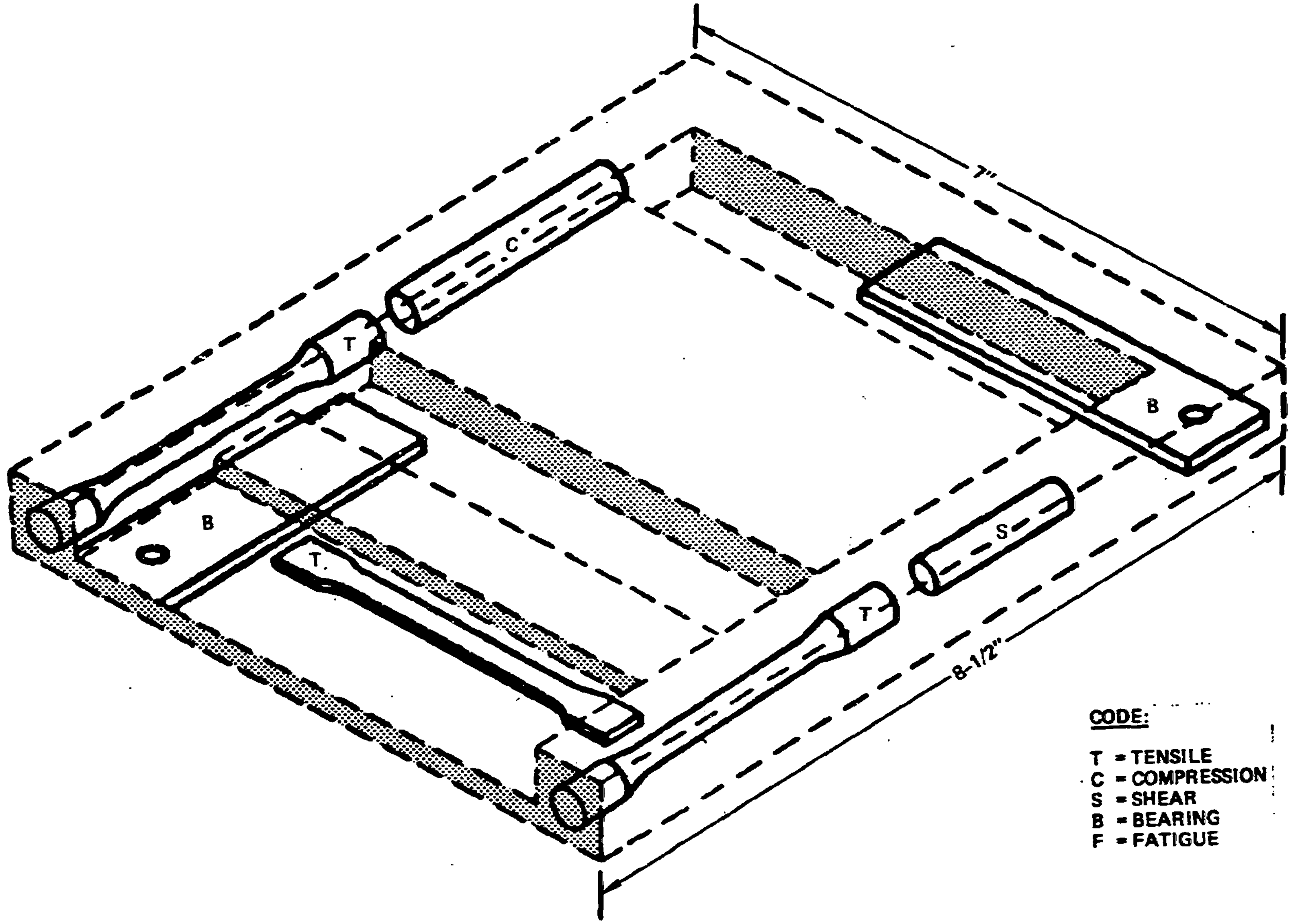
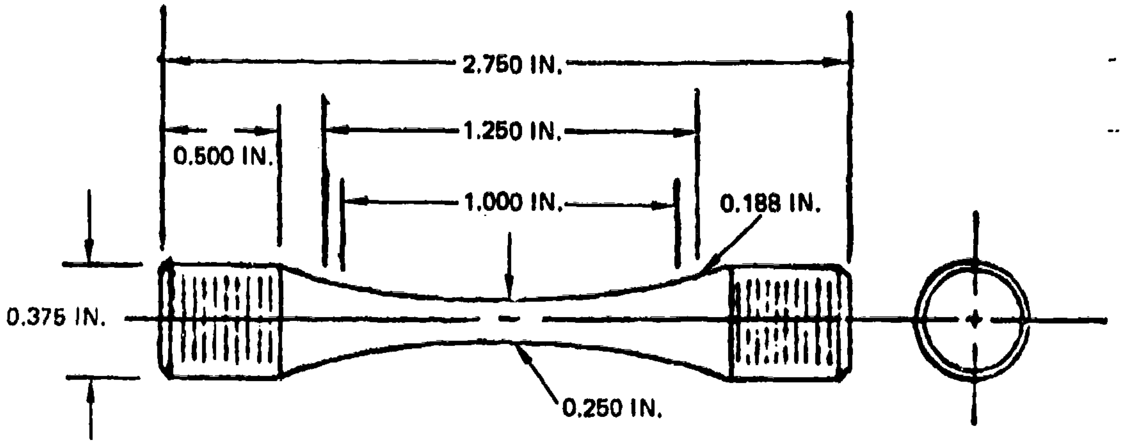
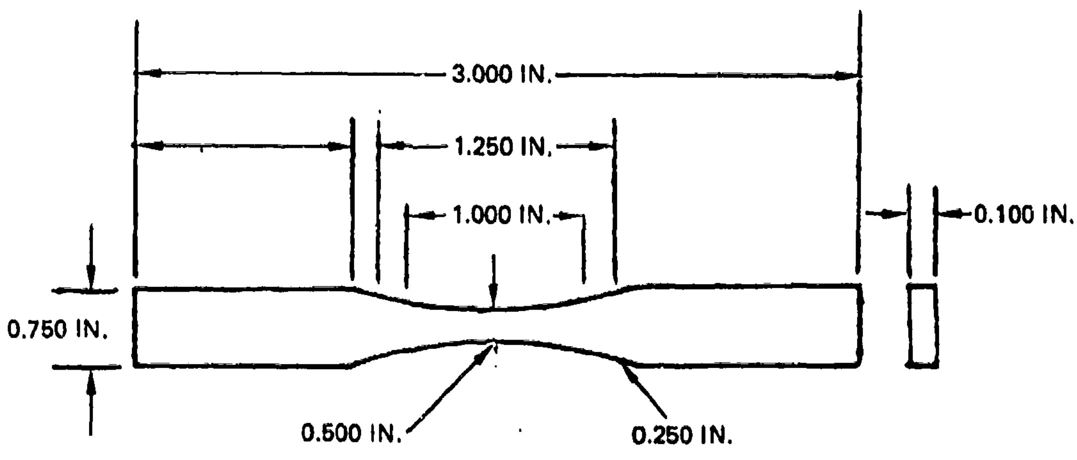


FIGURE 92. LOCATION OF TEST SPECIMENS IN NONDESIGNATED AREA OF STEP PLATE



ROUND R3 TENSILE TEST SPECIMEN



SUB-SIZE TENSILE TEST SPECIMEN

FIGURE 93. TENSILE SPECIMEN CONFIGURATION

2. Compression Tests

Compression specimens shown in Figure 94 were excised from step plates and tested per ASTM E9, "Compression Testing of Metallic Materials at Room Temperature."

3. Shear Tests

Shear coupons were excised from step plates, specimens machined to the configuration shown in Figure 94, and tested in accordance with the requirements of ASTM B565 "Shear Testing of Aluminum and Aluminum-Alloy Rivets and Cold-Heading Wire and Rods."

4. Bearing Tests

Bearing specimens shown in Figure 94 were excised from step plates and tested per ASTM E238, "Pin-type Bearing Test of Metallic Materials."

5. Fracture Toughness Tests

Compact tension specimens shown in Figures 95, and 96 were machined from separately cast test blocks and the specimen shown in Figure 97 was machined from the designated area of the step plate and tested per ASTM E399, "Plane Strain Fracture Toughness of Metallic Materials."

6. Crack Growth Tests

Testing of crack growth specimens depicted in Figure 98 were conducted in accordance with ASTM Standard E647, "Standard Method for Constant-Lead-Amplitude Fatigue Crack Growth Rates Above 10^8 in/cycle."

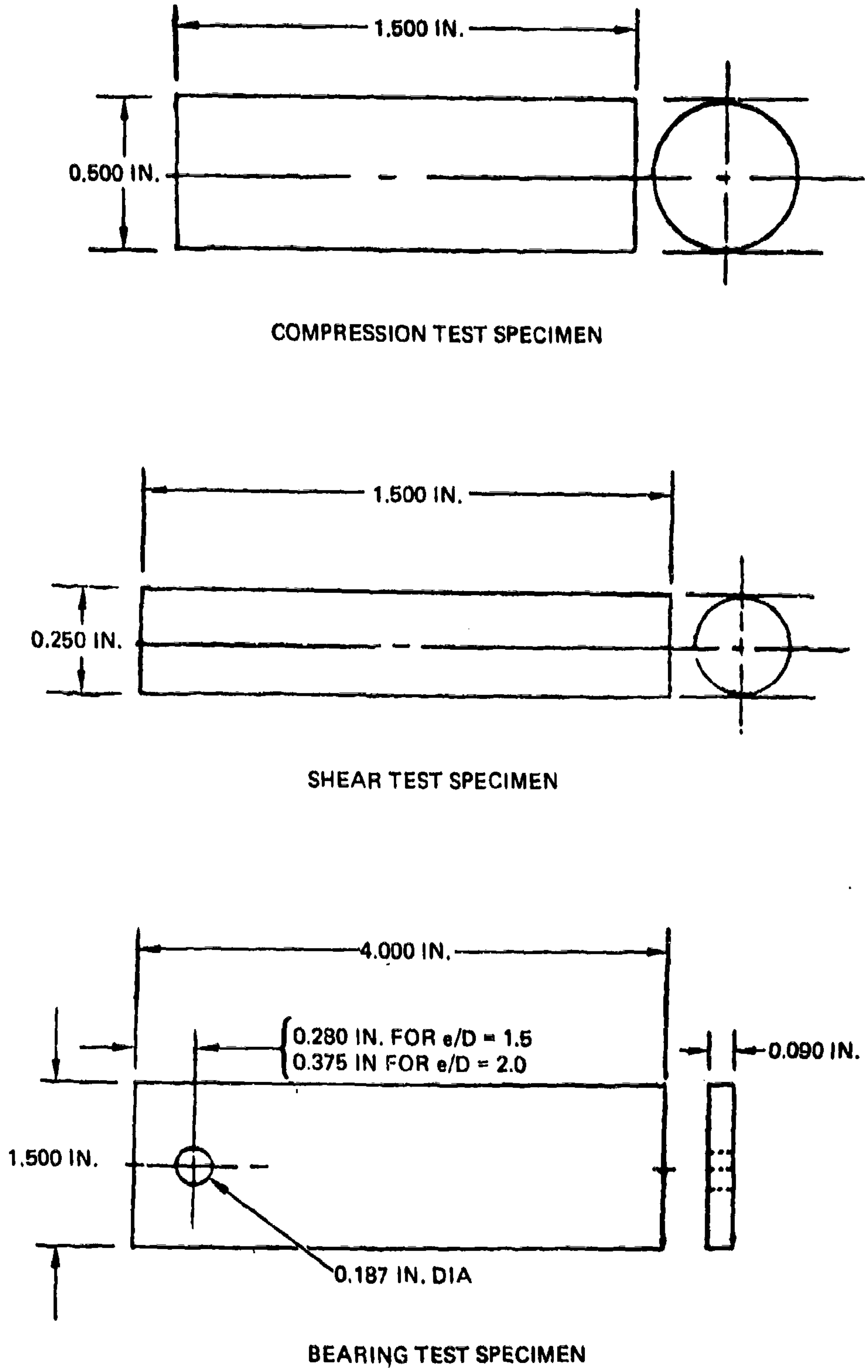


FIGURE 94. COMPRESSION, SHEAR, AND BEARING TEST SPECIMEN CONFIGURATIONS

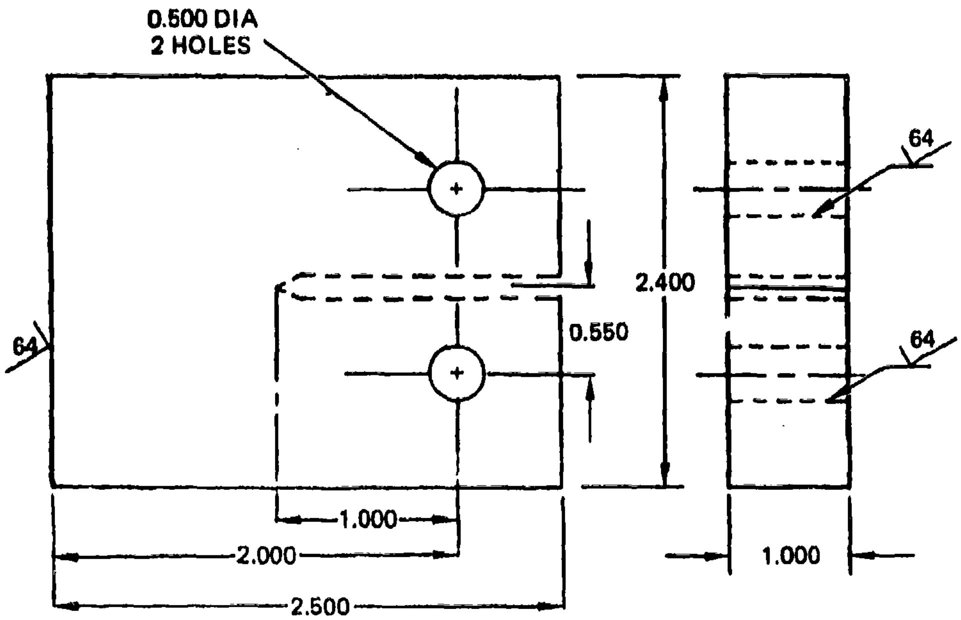


FIGURE 95. K_{IC} FRACTURE TOUGHNESS SPECIMEN EXCISED FROM SEPARATELY CAST BLOCK OF A201 ALLOY

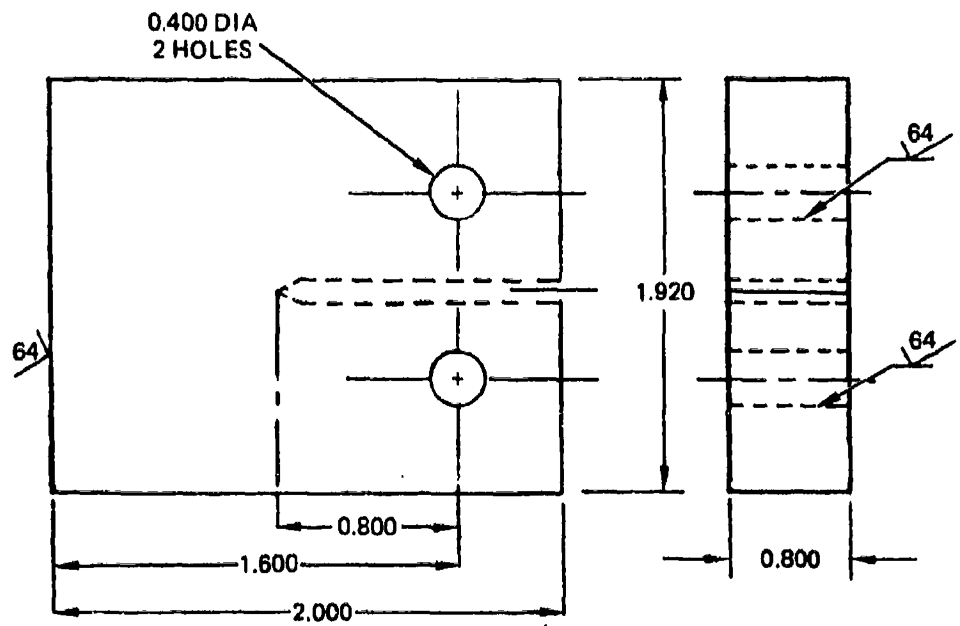


FIGURE 96. K_{IC} FRACTURE TOUGHNESS SPECIMEN EXCISED FROM SEPARATELY CAST BLOCK OF A357 ALLOY

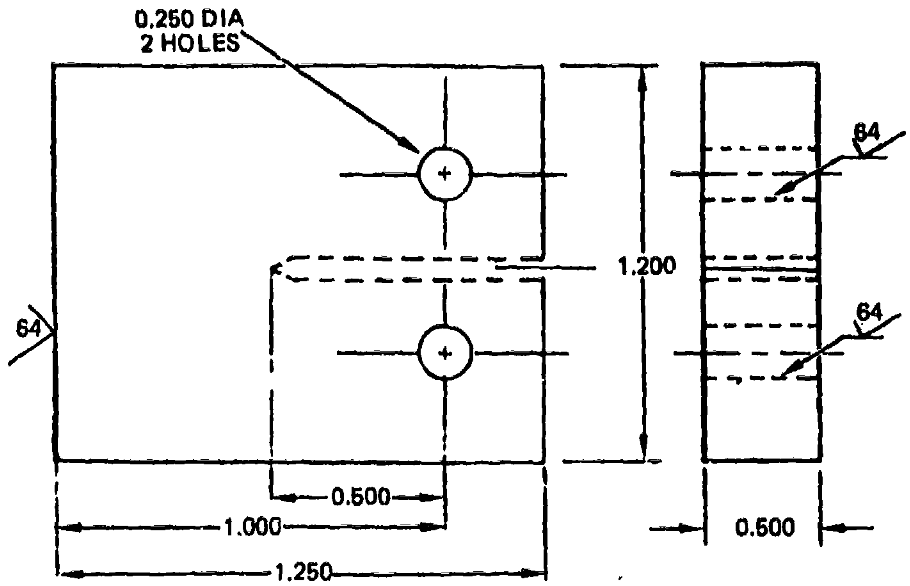


FIGURE 97. K_Q FRACTURE TOUGHNESS SPECIMEN EXCISED FROM STEP PLATE

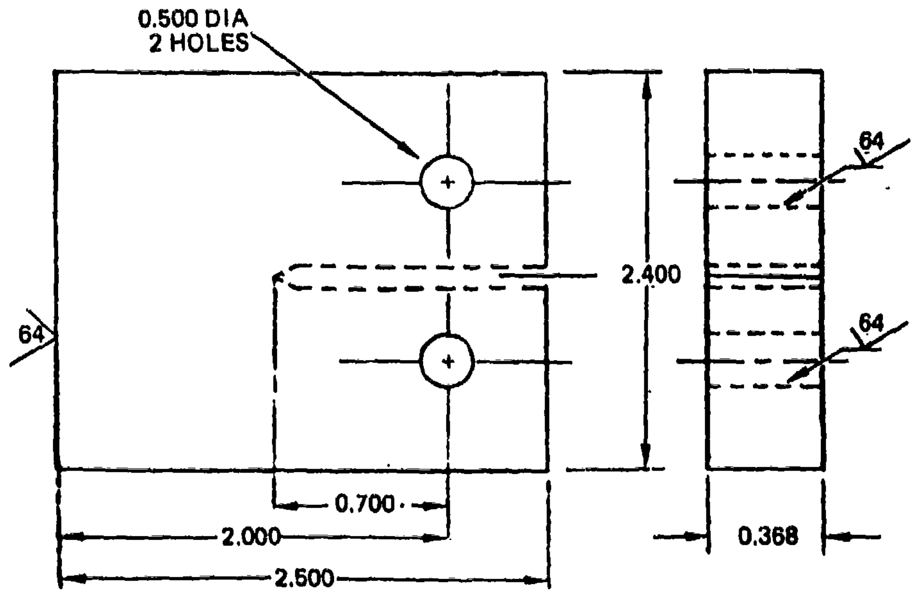


FIGURE 98. CRACK GROWTH SPECIMEN

7. Notched Fatigue Tests

Notched fatigue specimens shown in Figure 99 were excised from step plate castings and tested in accordance with ASTM E466, "Constant Amplitude Axial Fatigue Tests of Metallic Materials".

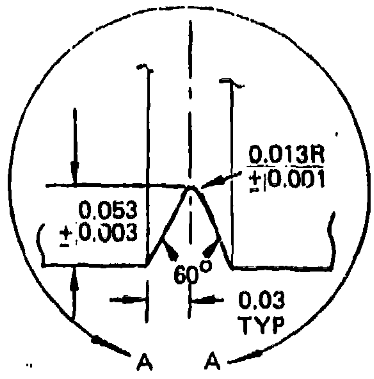
c. Results and Discussion

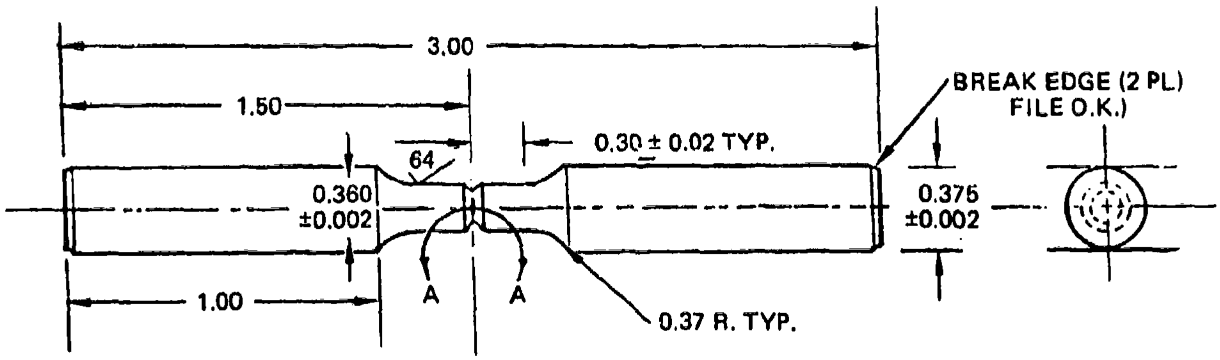
(1) A357 Alloy

(a) Tensile Properties

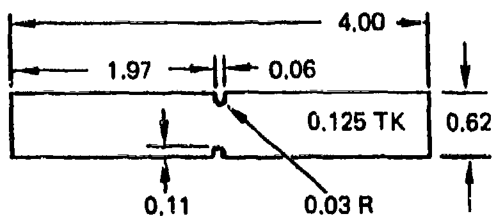
The tensile property data derived from step plates submitted by each foundry are shown in Tables 27, 28, 29 and 30. The average tensile properties for Magnesium Alloy Products and Teledyne Cast Products were as follows:

	Magnesium Alloy Products			Teledyne Cast Products		
	UTS (ksi)	YS (ksi)	e (%)	UTS (ksi)	YS (ksi)	e (%)
Designated Area						
Average	55.0	46.3	6	53.4	45.3	5
Range	53.2	43.8	3	50.7	42.2	3
	58.1	49.5	10	54.9	48.0	9
Non-Designated Area						
Average	54.4	45.6	6	50.5	43.7	3
Range	52.6	43.2	4	44.8	40.8	1
	56.0	47.9	11	52.5	45.4	5





ROUND NOTCHED FATIGUE SPECIMEN
(K_t = 3)



FLAT NOTCHED FATIGUE SPECIMEN
(K_t = 3)

FIGURE 99. NOTCHED FATIGUE (K_t = 3) SPECIMEN CONFIGURATIONS

TABLE 27. ROOM TEMPERATURE TENSILE PROPERTIES, MAGNESIUM ALLOY PRODUCTS, DESIGNATED AREA, A357 ALLOY

Item No.	Test Specimen Identification	TUS (ksi)	TYS (ksi)	e (%)
	A2237/3-13			
1	-T1	53.2	45.8	4
2	-T2	54.4	46.2	6
3	-T3	53.8	44.4	7
4	-T4	55.3	47.1	8
	B2237/3-14			
5	-T1	55.0	46.3	6
6	-T2	54.6	46.0	6
7	-T3	55.4	46.3	7
8	-T4	54.2	48.7	2
	D2237/3-15			
9	-T1	58.1	49.5	8
10	-T2	57.3	49.1	5
11	-T3	57.4	48.1	7
12	-T4	57.6	48.9	6
	A2244/2-17			
13	-T1	54.2	45.0	7
14	-T2	54.4	45.4	6
15	-T3	54.4	46.2	5
16	-T4	54.4	47.0	5
	A2244/2-18			
17	-T1	54.4	44.8	6
18	-T2	55.5	46.0	7
19	-T3	54.8	45.6	6
20	-T4	54.6	47.5	4
	A2244/2-19			
21	-T1	54.3	45.7	6
	D2244/2-20			
22	-T1	56.6	47.3	8
23	-T2	57.6	47.7	10
24	-T3	56.2	45.8	7
	A2250/4-21			
25	-T1	55.4	45.6	8
26	-T2	56.0	46.2	8
27	-T3	55.2	45.6	6
28	-T4	54.6	48.4	4

TABLE 27. ROOM TEMPERATURE TENSILE PROPERTIES, MAGNESIUM ALLOY PRODUCTS, DESIGNATED AREA, A357 ALLOY (Continued)

Item No.	Test Specimen Identification	TUS (ksi)	TYS (ksi)	e (%)
	B2250/4-22			
29	-T1	55.2	46.1	7
30	-T2	55.0	46.4	7
31	-T3	54.8	45.8	6
32	-T4	53.6	47.7	3
	B2250/4-24			
33	-T1	55.4	46.7	6
	A2256/4-29			
34	-T1	54.6	44.8	6
35	-T2	54.8	45.0	8
36	-T3	54.1	44.8	8
37	-T4	56.2	47.0	8
	B2256/4-30			
38	-T1	53.9	44.6	8
39	-T2	53.4	44.6	7
40	-T3	54.6	45.6	7
41	-T4	55.2	46.7	7
	H2256/4-31			
42	-T1	54.4	45.3	7
	D2256/4-32			
43	-T1	55.0	46.8	6
44	-T2	56.4	47.7	9
45	-T3	55.6	46.0	6
	D2258/4-34			
46	-T1	53.4	47.5	3
47	-T2	55.4	47.4	6
48	-T3	55.2	46.2	6
49	-T4	54.8	48.1	4
	B2258/4-35			
50	-T1	54.0	45.8	6
51	-T2	54.2	46.0	6
52	-T4	52.6	47.1	3
	H2258/4-36			
53	-T1	53.6	45.2	8
	C2301/5-37			
54	-T1	54.4	43.8	10

TABLE 27. ROOM TEMPERATURE TENSILE PROPERTIES, MAGNESIUM ALLOY PRODUCTS, DESIGNATED AREA, A357 ALLOY (Concluded)

Item No.	Test Specimen Identification	TUS (ksi)	TYS (ksi)	e (%)
55	G2301/3-38 -T1	55.7	45.8	8
56	G2301/3-39 -T1	55.2	44.6	8

TABLE 28. ROOM TEMPERATURE TENSILE PROPERTIES, MAGNESIUM ALLOY PRODUCTS, NON-DESIGNATED AREA, A357 ALLOY

Item No.	Test Specimen Identification	TUS (ksi)	TYS (ksi)	e (%)
1	F2237/3-13-T6	53.9	45.5	7
2	-T7	53.4	44.6	7
3	-T8	53.6	45.5	11
4	F2237/3-14-T6	54.6	46.0	6
5	-T7	53.4	46.2	3
6	F2237/3-15-T6	54.2	45.0	6
7	-T7	54.0	46.0	6
8	F2237/3-16-T6	55.6	47.9	5
9	F2244/2-17-T6	55.0	46.8	6
10	-T7	55.0	45.3	9
11	-T8	52.6	44.6	9
12	F2244/2-18-T6	55.1	45.5	7
13	-T7	55.2	47.1	5
14	F2244/2-19-T6	54.4	45.0	6
15	F2244/2-20-T6	55.6	47.3	6
16	F2250/4-21-T6	55.4	46.2	6
17	-T7	56.0	46.8	6
18	-T8	55.2	47.2	9
19	F2250/4-22-T6	54.4	47.1	4
20	-T7	55.0	47.0	6
21	F2250/4-24-T6	54.4	46.3	4
22	F2256/4-29-T6	54.4	44.5	9
23	-T7	54.8	44.8	8
24	-T8	54.1	45.1	10
25	F2256/4-30-T6	54.0	45.2	8
26	-T7	53.6	44.0	6
27	F2256/4-31-T6	54.3	44.2	9
28	F2256/4-32-T6	55.5	46.5	7
29	F2258/4-34-T6	55.2	46.6	7
30	-T7	54.4	46.0	6
31	-T8	54.5	46.1	9
32	F2258/4-35-T6	53.4	43.2	8
33	-T7	53.4	44.2	6
34	F2258/4-36-T6	52.5	43.2	6
35	-T7	53.3	43.9	7
36	F2301/3-37-T6	54.6	46.3	6
37	F2301/3-38-T6	54.1	45.3	7
38	F2301/3-39-T6	54.6	45.0	8

TABLE 29. ROOM TEMPERATURE TENSILE PROPERTIES, TELEDYNE CAST PRODUCTS, DESIGNATED AREA, A357 ALLOY

Item No.	Test Specimen Identification	TUS (ksi)	TYS (ksi)	e (%)
1	A79-T1	52.2	42.7	8
2	-T2	52.5	43.0	8
3	A80-T1	50.7	42.4	6
4	-T2	50.9	42.2	8
5	-T3	51.3	42.7	7
6	B85-T1	53.9	45.0	6
7	-T2	53.3	45.6	5
8	-T3	52.8	46.4	4
9	T4	52.7	46.8	3
10	A86-T1	53.3	44.9	6
11	-T2	53.3	45.3	5
12	-T3	52.5	45.7	4
13	-T4	51.7	45.7	3
14	A87-T1	53.7	45.7	4
15	-T2	54.9	46.3	6
16	-T3	54.0	46.6	5
17	-T4	53.7	46.7	5
18	H88-T1	54.7	46.5	6
19	B89-T1	53.9	43.9	9
20	B90-T1	54.7	44.3	8
21	-T2	53.5	44.6	6
22	-T3	52.8	44.9	5
23	-T4	52.5	45.4	4
24	A91-T1	53.7	44.3	6
25	-T2	53.5	45.5	4
26	-T3	51.9	47.9	3
27	-T4	52.9	46.6	3
28	B92-T1	52.9	45.2	4
29	-T2	53.9	45.7	5
30	-T3	54.7	47.1	4
31	-T4	54.3	48.0	4
32	H93-T1	54.4	45.1	8
33	B94-T1	54.4	45.2	7
34	-T2	53.9	44.9	6
35	-T3	53.1	46.2	4
36	-T4	52.7	47.1	3
37	A95-T1	53.5	46.2	3
38	-T2	53.5	46.5	4
39	-T3	54.2	46.7	5
40	-T4	53.7	46.7	5
41	A96-T1	54.1	44.2	7
42	H97-T1	54.2	44.3	8
43	B98-T1	54.3	43.9	7
44	-T2	52.2	44.3	5
45	-T3	52.7	45.1	4

TABLE 29. ROOM TEMPERATURE TENSILE PROPERTIES, TELEDYNE CAST PRODUCTS, DESIGNATED AREA, A357 ALLOY (Concluded)

Item No.	Test Specimen Identification	TUS (ksi)	TYS (ksi)	e (%)
46	-T4	54.1	44.8	7
47	A99-T1	54.7	44.3	8
48	-T2	53.7	45.0	6
49	-T3	53.9	45.5	6
50	-T4	53.7	44.9	6

TABLE 30. ROOM TEMPERATURE TENSILE PROPERTIES, TELEDYNE CAST PRODUCTS, NON-DESIGNATED AREA, A357 ALLOY

Item No.	Test Specimen Identification	TUS (ksi)	TYS (ksi)	e (%)
1	A79-T6	44.8	40.8	2
2	-T7	48.2	41.6	3
3	A80-T6	47.3	41.4	3
4	-T7	47.4	41.4	3
5	A81-T6	49.1	42.5	4
6	B85-T6	51.3	44.5	3
7	-T7	51.5	44.3	3
8	A86-T6	51.2	43.9	4
9	-T7	51.3	43.9	4
10	A87-T6	52.5	45.4	4
11	-T7	51.1	44.9	3
12	H88-T6	52.1	44.9	4
13	B89-T6	50.5	44.3	3
14	B90-T6	51.1	44.1	4
15	-T7	51.0	43.6	5
16	A91-T6	49.1	43.1	2
17	-T7	52.1	44.4	5
18	B92-T6	49.5	43.7	2
19	-T7	52.7	45.3	4
20	H93-T6	50.3	44.2	3
21	-T7	52.1	44.5	4
22	B94-T6	49.3	41.8	3
23	-T7	50.9	44.3	3
24	A95-T6	51.0	45.2	3
25	-T7	52.9	45.2	4
26	A96-T6	50.3	42.2	4
27	H97-T6	49.9	43.5	3
28	-T7	52.5	45.3	4
29	B98-T6	50.5	43.9	4
30	-T7	51.9	44.3	5
31	A99-T6	48.9	43.0	1
32	-T7	51.1	42.7	4

The similarity of tensile properties in designated and non-designated areas of plates from Magnesium Alloy Products reflected a similarity of quality in the two areas. Each foundry was asked to downgrade the radiographic quality in the non-designated areas from Grade B to Grade C. This was only partially accomplished. Since the non-designated area from which most of the tensile specimens were excised was 3/4 inch thick, the radiographic flaws may have been removed during the machining of the 1/4-inch diameter R_3 tensile specimen. Some evidence of quality degradation was shown in the lower properties of non-designated areas of the Teledyne Cast Products Company step plates. The effect of radiographic unsoundness on tensile properties is discussed later in the report.

(b) Compression, Bearing, and Shear Properties

The average compression yield strength values were as follows:

	Designated Areas CYS (ksi)	Non-designated Areas CYS (ksi)
Magnesium Alloy Products	48.5	47.2
Teledyne Cast Products	45.8	45.6
Combined	47.2	46.4

The test results are shown in Tables 31, 32, 33 and 34 along with correlated tensile property values.

The average shear ultimate strength values were as follows:

	Designated Areas SUS (ksi)	Nondesignated Areas SUS (ksi)
Teledyne Cast Products	34.1	33.8
Magnesium Alloy Products	34.7	34.2
Combined	34.4	34.0

The test values and correlated tensile properties are shown in Tables 31, 32, 33 and 34.

TABLE 31. COMPRESSION, SHEAR, AND BEARING PROPERTIES OF A357 STEP PLATES MAGNESIUM ALLOY PRODUCTS, DESIGNATED AREA

Compression Yield Strength (CYS):

Item No.	Specimen Identification	CYS (ksi)	TYS (ksi)	Identification
			Tensile Ultimate Strength (Tus) or Tensile Yield Strength (Tys) of Companion Tensile Specimen	
1	A2237/3-13-C1	47.6	47.1	A2237/3-13-T4
2	A2244/2-17-C1	47.9	47.0	A2237/3-13-T4
3	A2256/4-29-C1	47.6	47.0	A2256/4-29-T4
4	A2258/4-34-C1	50.0	48.1	A2258/4-34-T4
5	A2250/4-21-C1	49.4	48.4	A2250/4-21-T4

Shear Ultimate Strength (SUS):

Item No.	Specimen Identification	SUS (ksi)	TUS (ksi)	Identification
1	A2237/3-13-S1	33.9	55.3	A2237/3-13-T4
2	A2244/2-17-S1	35.0	54.4	A2233/2-17-T4
3	A2256/4-29-S1	34.6	56.2	A2256/4-29-T4
4	A2258/4-34-S1	34.9	54.8	A2258/4-34-T4
5	A2250/4-21-S1	35.2	54.6	A2250/4-21-T4

Bearing Yield and Ultimate Strength Properties (BYS and BUS):

Item No.	Specimen Identification	BYS (ksi)	BUS (ksi)	TYS (ksi)	TUS (ksi)	Identification
		e/D = 1.5				
1	B2237/3-14-B1	75.4	94.2	48.7	54.2	B2237/3-14-T4
2	B2250/4-22-B1	75.8	95.0	47.7	53.6	B2250/4-22-T4
3	B2244/2-18-B1	75.9	95.7	47.5	54.6	B2244/2-18-T4
4	B2256/4-30-B1	74.2	92.8	45.4	54.3	B2256/4-30-T4
5	B2258/4-35-B1	74.7	91.8	47.1	52.6	B2258/4-35-T4
		e/D = 2.0				
1	A2237/3-13-B1	83.3	117.2	47.1	55.3	A2237/3-13-T4
2	A2244/2-17-B1	88.0	107/5	47.0	54.4	A2244/2-17-T4
3	A2250/4-21-B1	85.8	122.2	48.4	54.6	A2250/4-21-T4
4	A2256/4-29-B1	89.4	119.8	47.0	56.2	A2256/4-29-T4
5	A2258/4-34-B1	89.8	117.4	48.1	54.8	A2258/4-34-T4

TABLE 32. COMPRESSION, SHEAR, AND BEARING PROPERTIES OF A357 STEP PLATES MAGNESIUM ALLOY PRODUCTS, NON-DESIGNATED AREA

Compression Yield Strength (CYS)

Item No.	Specimen Identification	CYS (ksi)	TYS (ksi)	Identification
			Ultimate and Yield Strength of Companion Tensile Specimen	
1	F2237/3-13-C2	46.2	45.5	F2237/3-13-T6
2	F2244/2-17-C2	46.8	46.8	F2237/3-17-T6
3	F2250/4-21-C2	48.0	46.2	F2250/4-21-T6
4	F2256/4-29-C2	46.5	44.5	F2250/4-21-T6
5	F2258/4-34-C2	48.6	46.6	F2258/4-34-T6

Shear Ultimate Strength (SUS)

Item No.	Specimen Identification	SUS (ksi)	TUS (ksi)	Identification
1	F2237/3-13-S2	33.0	53.4	F2237/3-13-T7
2	F2244/2-17-S2	33.8	55.0	F2244/2-17-T7
3	F2250/4-21-S2	34.9	56.0	F2250/4-21-T7
4	F2256/4-29-S2	34.5	54.8	F2256/4-29-T7
5	F2258/4-34-S2	34.9	54.4	F2258/4-34-T7

Bearing Yield and Ultimate Strength Properties (BYS and BUS)

Item No.	Specimen Identification	BYS (ksi)	BUS (ksi)	TYS (ksi)	TUS (ksi)	Identification
		e/D = 1.5				
1	F2237/3-13-B2	72.3	89.6	45.5	53.6	F2237/3-13-T8
2	F2244/2-17-B2	72.4	90.5	44.6	52.6	F2244/2-17-T8
3	F2250/4-21-B2	75.7	94.8	47.2	55.2	F2250/4-21-T8
4	F2256/4-29-B2	71.9	88.8	45.1	54.1	F2256/4-29-T8
5	F2258/4-34-B2	74.5	94.1	46.1	54.5	F2258/4-34-T8
		e/D = 2.0				
1	F2237/3-13-B3	82.6	113.3	44.6	53.4	F2237/3-13-T7
2	F2244/2-17-B3	89.3	115.0	45.3	55.0	F2244/2-17-T7
3	F2250/4-21-B3	87.1	116.7	46.8	56.0	F2250/4-21-T7
4	F2256/4-29-B3	91.9	119.8	44.8	54.8	F2256/4-29-T7
5	F2258/4-34-B3	90.5	117.1	46.0	54.4	F2258/4-34-T7

TABLE 33. COMPRESSION, SHEAR, AND BEARING PROPERTIES OF A357 STEP PLATES TELEDYNE CAST PRODUCTS, DESIGNATED AREA

Compressive Yield Strength (CYS) — Yield and Ultimate Strength of Companion Tensile Specimen

Item No.	Specimen Identification	(CYS) (ksi)	TYS (ksi)	Identification
1	A86-C1	46.3	45.7	A86-T4
2	A87-C1	45.4	46.7	A87-T4
3	A91-C1	46.1	46.6	A91-T4
4	A95-C1	47.1	46.7	A95-T4
5	A99-C1	44.1	44.3	A99-T4

Shear Ultimate Strength (SUS)

Item No.	Specimen Identification	(SUS) (ksi)	TUS (ksi)	Identification
1	A86-S1	33.7	51.7	A86-T4
2	A87-S1	33.9	53.7	A87-T4
3	A91-S1	34.2	52.9	A91-T4
4	A95-S1	34.5	53.7	A95-T4
5	A99-S1	34.0	53.7	A99-T4

Bearing Yield and Ultimate Strength Properties (BYS and BUS)

Item No.	Specimen Identification	BYS (ksi)	BUS (ksi)	TYS (ksi)	TUS (ksi)	Identification
		e/D = 1.5				
1	B85-B1	74.0	92.4	46.8	52.7	B85-T4
2	B90-B1	72.3	91.6	45.4	52.5	B90-T4
3	B92-B1	78.3	93.4	48.0	54.3	B92-T4
4	B94-B1	73.0	91.6	45.2	54.4	B94-T4
5	B98-B1	69.4	90.6	44.8	54.1	B98-T4
		e/D = 2.0				
1	A86-B1	84.6	117.1	45.7	51.7	A86-T4
2	A87-B1	86.4	118.3	46.7	53.7	A87-T4
3	A91-B1	89.4	118.1	46.6	52.9	A91-T4
4	A95-B1	88.4	119.0	46.7	53.7	A95-T4
5	A99-B1	82.0	114.6	44.3	53.7	A99-T4

TABLE 34. COMPRESSION, SHEAR, AND BEARING PROPERTIES OF A357 STEP PLATES TELEDYNE CAST PRODUCTS, NON-DESIGNATED AREA

Compressive Yield Strength (CYS) — Yield and Ultimate Strength of Companion Tensile Specimen

Item No.	Specimen Identification	(CYS) (ksi)	TYS (ksi)	Identification
1	F86-C2	46.4	43.9	F86-T6
2	F87-C2	45.6	45.4	F87-T6
3	F91-C2	45.9	43.1	F91-T6
4	F95-C2	46.2	45.2	F95-T6
5	F99-C2	44.1	43.0	F99-T6

Shear Ultimate Strength (SUS)

Item No.	Specimen Identification	(SUS) (ksi)	TUS (ksi)	Identification
1	F86-S2	33.0	51.3	F86-T7
2	F87-S2	34.4	51.1	F87-T7
3	F91-S2	34.2	52.1	F91-T7
4	F95-S2	34.1	52.9	F95-T7
5	F99-S2	33.3	51.1	F99-T7

Bearing Yield and Ultimate Strength Properties (BYS and BUS)

Item No.	Specimen Identification	BYS (ksi)	BUS (ksi)	TYS (ksi)	TUS (ksi)	Identification
		e/D = 1.5				
1	F86-B3	72.7	90.9	43.9	51.2	F86-T6
2	F87-B2	88.5	92.6	45.4	52.5	F87-T6
3	F91-B2	68.8	90.7	43.1	49.1	F91-T6
4	F95-B2	72.8	93.3	45.2	51.0	F95-T6
5	F99-B2	71.0	92.7	43.0	48.9	F99-T6
		e/D = 2.0				
1	F86-B2	85.7	117.0	43.9	51.3	F86-T7
2	F87-B3	88.1	117.8	44.9	51.1	F87-T7
3	F91-B3	87.2	116.9	44.4	52.1	F91-T7
4	F95-B3	86.2	116.9	45.2	52.9	F95-T7
5	F99-B3	83.9	113.3	42.7	51.1	F99-T7

The bearing ultimate and yield strength properties at edge distances/diameter of hole (e/D) ratios of 1.5 and 2.0 are shown in Tables 31, 32, 33 and 34; companion tensile properties of the same material are also shown. The average bearing ultimate strength (BUS) and yield strength (BYS) were as follows:

	Designated Areas				Non-designated Areas			
	e/D ratio 1.5		e/D ratio 2.0		e/D ratio 1.5		e/D ratio 2.0	
	BUS (ksi)	BYS (ksi)	BUS (ksi)	BYS (ksi)	BUS (ksi)	BYS (ksi)	BUS (ksi)	BYS (ksi)
Magnesium Alloy Products	93.9	75.2	117.2	83.3	91.6	73.4	113.3	82.6
Teledyne Cast Products	91.9	73.4	117.4	86.2	92.4	74.8	116.4	86.2
Combined	92.9	74.3	117.3	84.7	92.0	74.1	114.8	84.4

(c) Design Property Determination - Tensile Properties

Magnesium Alloy Products and Teledyne Cast Products provided data on 106 tensile tests of designated areas in 36 step plate castings that were produced in 11 melts and 4 heat treatment lots. Statistical A and B tensile property values determined by Battelle Columbus Institute for sand composite A357-T6 aluminum alloy castings, were as follows:

	Designated Area Property Value	
	A	B
Ftu (ksi)	50.6	52.2
Fty (ksi)	42.1	43.7

Similar design allowable tensile property values could not be determined in non-designated areas of the step plates, since the values from the two suppliers varied significant from each other so that they could not be combined into one population. Data available for the separate populations were insufficient for the determination of A or B allowables.

Compression, Bearing, and Shear Property Ratio - All property values were compared to a companion tensile property value to establish a property ratio. The average ratio determined for each property was as follows:

		Magnesium Alloy Products		Teledyne Cast Products	
Property Ratio	e/D Ratio	Designated Area 0.500 inch	Non-designated Area 0.750 inch	Designated Area 0.500 inch	Non-designated Area 0.750 inch
CYS/TYS		1.021	1.028	0.996	1.035
SUS/TUS		0.631	0.625	0.641	0.654
BUS/TUS	1.5	1.743	1.696	1.715	1.822
BYS/TYS	1.5	1.591	1.605	1.594	1.693
BUS/TUS	2.0	2.122	2.127	2.210	2.251
BYS/TYS	2.0	1.837	1.941	1.873	1.950

The following results were obtained by combining the ratios of test results from each foundry for designated and non-designated casting areas.

Property Ratio	e/D Ratio	Magnesium Alloy Products	Teledyne Cast Products	Combined
CYS/TYS		1.015	0.999	1.011
SUS/TUS		0.621	0.640	0.632
BUS/TUS	1.500	1.697	1.728	1.721
BYS/TYS	1.500	1.584	1.578	1.589
BUS/TUS	2.000	2.084	2.203	2.147
BYS/TYS	2.000	1.837	1.883	1.873

(d) Proposed Specification Values

The recommended minimum specification values for designated areas of A357-T6 sand composite castings are as follows:

50 ksi tensile ultimate strength
40 ksi tensile yield strength
3 percent elongation

The tensile ultimate strength and tensile yield strength values are based on the A values statistically determined from step plate data. The 3-percent elongation value was based on the lowest value that repeated in the data used for TUS and TYS determinations. The recommended minimum specification values for A357-T6 non-designated casting areas are as follows:

45 ksi tensile ultimate strength
38 ksi tensile yield strength
2 percent elongation

These values are based on 10 percent reduction of TUS from the 50 ksi required in designated areas. The 10-percent reduction was allowed to account for the variations in DAS and radiographic quality in these areas of the castings. A reduction of yield strength to 38 ksi, 2 ksi less than the 40 ksi required in designated areas, was judged adequate to account for any metallurgical differences that would retard aging in these areas of the casting. Of the 70 tests from the non-designated areas of the step plates, a 2 percent elongation value was the lowest value that repeated in more than one test.

(e) Design Property Table

The proposed design allowable property information (Table 35) was derived by using the proposed minimum specification strength values of designated and non-designated areas of A357-T6 casting material, and the derived ratios for determining compression, shear, and bearing values.

(f) Elevated Temperature Tensile Properties

Elevated tensile testing was performed at temperatures of 250F, 300F, 350F, and 400F. The results are shown in Tables 36 and 37 and are compared in Figure 100. In general, all properties decreased with increased temperatures, with the exception of elongation where its value remained fairly constant in the range of 350F to 400F.

TABLE 35. PROPOSED MIL-HDBK-5 TABLE FOR DESIGN MECHANICAL AND PHYSICAL PROPERTIES OF A357.0 ALUMINUM ALLOY CASTING

Specification	(Proposed AMS XXXX)		
Form	Casting		
Condition	T6		
Thickness, in.	0.500		
Location	Designated Area		Non-designated Area
Basis	A	B	S
Mechanical properties:			
F_{tu}, ksi	50	51	45
F_{ty}, ksi	40	43	36
F_{cy}, ksi	40	43	36
F_{su} ksi	31	32	28
F_{bru}, ksi:			
(e/D = 1.5)	86	88	77
(e/D = 2.0)	107	109	96
F_{bry}, ksi:			
(e/D = 1.5)	63	68	57
(e/D = 2.0)	75	80	67
e, per cent	3		2
E, 10^3 ksi	10.4		
E_c, 10^3 ksi	10.5		
G, 10^3 ksi	3.9		
	0.33		
Physical properties:			
, lb/in.^{3}	0.097		
C, Btu/(lb)(F)	0.23 (at 212F)		
K, Btu/[(hr)(ft^2((F)/ft]	88 (at 77F)		
a, 10^{-6}in./in./F	12.0 (68 to 212F)		

Table 36. ELEVATED TEMPERATURE TENSILE PROPERTIES, MAGNESIUM ALLOY PRODUCTS, A357 ALLOY

Specimen Identification	Test Temperature, (F)	Tensile Properties TUS, (ksi)	TYS, (ksi)	e, (%)
13T5	250	45.2	38.3	9
14T5	250	45.3	38.2	12
17T5	250	45.2	38.7	10
18T5	300	41.4	36.8	7
21T5	300	42.3	37.7	8
22T5	350	39.3	36.3	9
29T5	350	39.3	36.0	8
30T5	350	38.7	35.5	7
34T5	400	34.9	31.9	6
35T5	400	35.2	32.8	8

Table 37. ELEVATED TEMPERATURE TENSILE PROPERTIES, TELEDYNE CAST PRODUCTS, A357 ALLOY

Specimen Identification	Test Temperature, (F)	Tensile Properties TUS, (ksi)	TYS, (ksi)	e, (%)
85T-5	250	45.7	40.3	11
86T-5	250	45.6	40.4	10
87T-5	300	42.1	36.9	10
90T-5	300	42.1	36.8	10
91T-5	300	42.5	37.3	10
92T-5	350	39.9	36.7	8
94T-5	350	39.6	35.7	7
95T-5	400	37.2	35.4	8
98T-5	400	36.4	34.4	8
99T-5	400	37.3	34.9	0

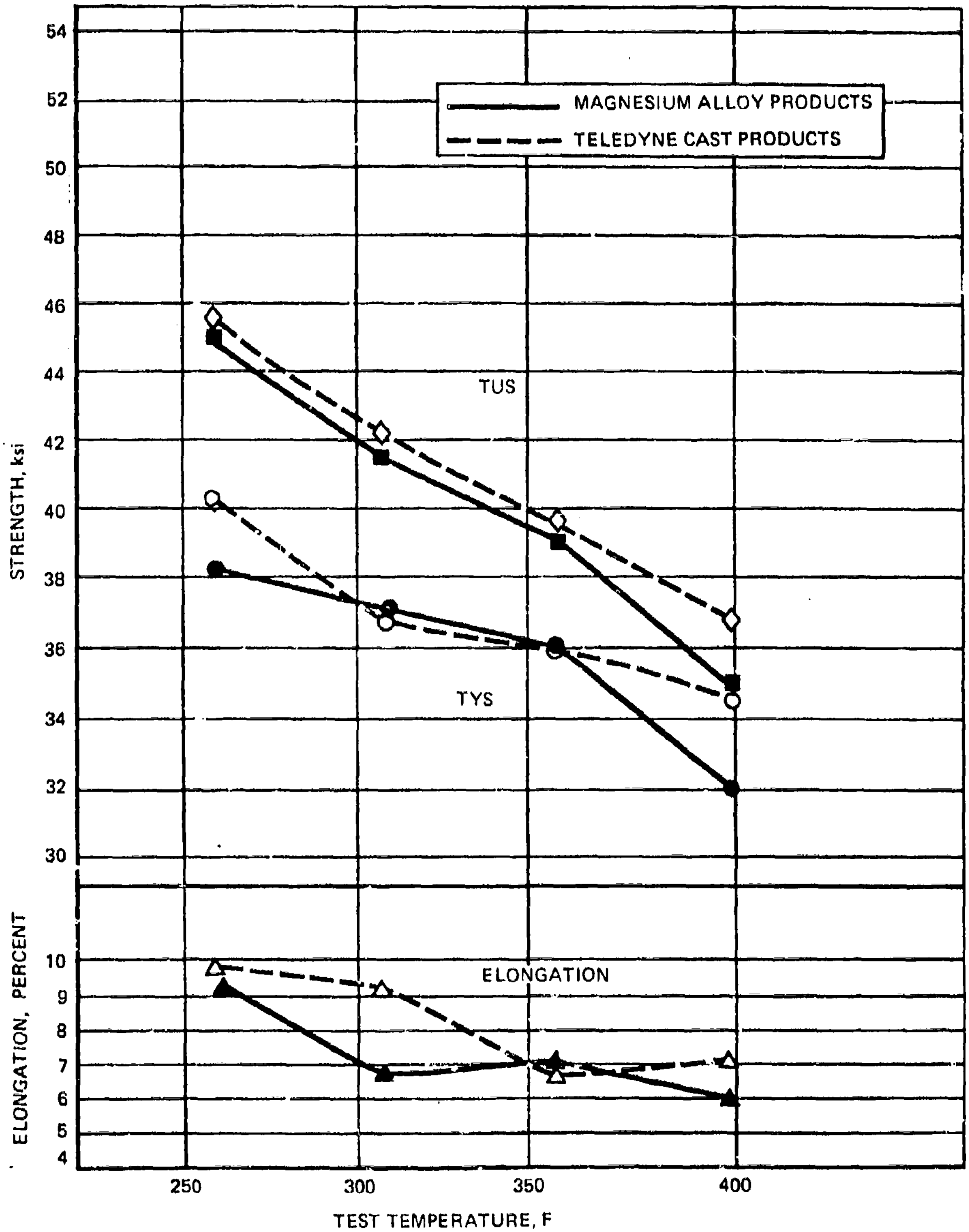


FIGURE 100. EFFECT OF ELEVATED TEMPERATURES ON THE TENSILE PROPERTIES OF A357-T6 MATERIAL

(g) Fracture Toughness Properties

The fracture toughness properties obtained from a separately cast test block, 0.8-inch thick, were as follows:

Specimen	Yield Strength (ksi)	Fracture Toughness (ksi in)	Reason Not Valid	Producing Foundry
9193-1	46.1	25.4	b	Teledyne Cast Products
9193-4	46.0	26.6	c, d	Teledyne Cast Products
2237-3-7	44.1	26.7	a, b, c, d	Magnesium Alloy
2244-2-8	45.2	25.7	a, c, d	Magnesium Alloy
2258-4-9	44.1	26.4	a, b, c, d	Magnesium Alloy
	Average	26.1		

---

a = Crack length >0.55 W

b = Crack length at surface 1 is less than 85 percent of average crack length

c = Crack length at surface 2 is less than 85 percent of average crack length

d = Thickness is less than 2.5 $\left(\frac{KQ}{YS}\right)^2$

The effect of weld repair and radiographic unsoundness on the fracture toughness properties is discussed later in the report.

(h) Notched Fatigue Properties

The notched fatigue results are plotted in Figure 101. These specimens were taken from the designated area of the step plate castings. The endurance limit for the material appears to be between 12.5 and 15 ksi. The effect of weld repair and radiographic unsoundness on the fatigue properties is discussed later in the report.

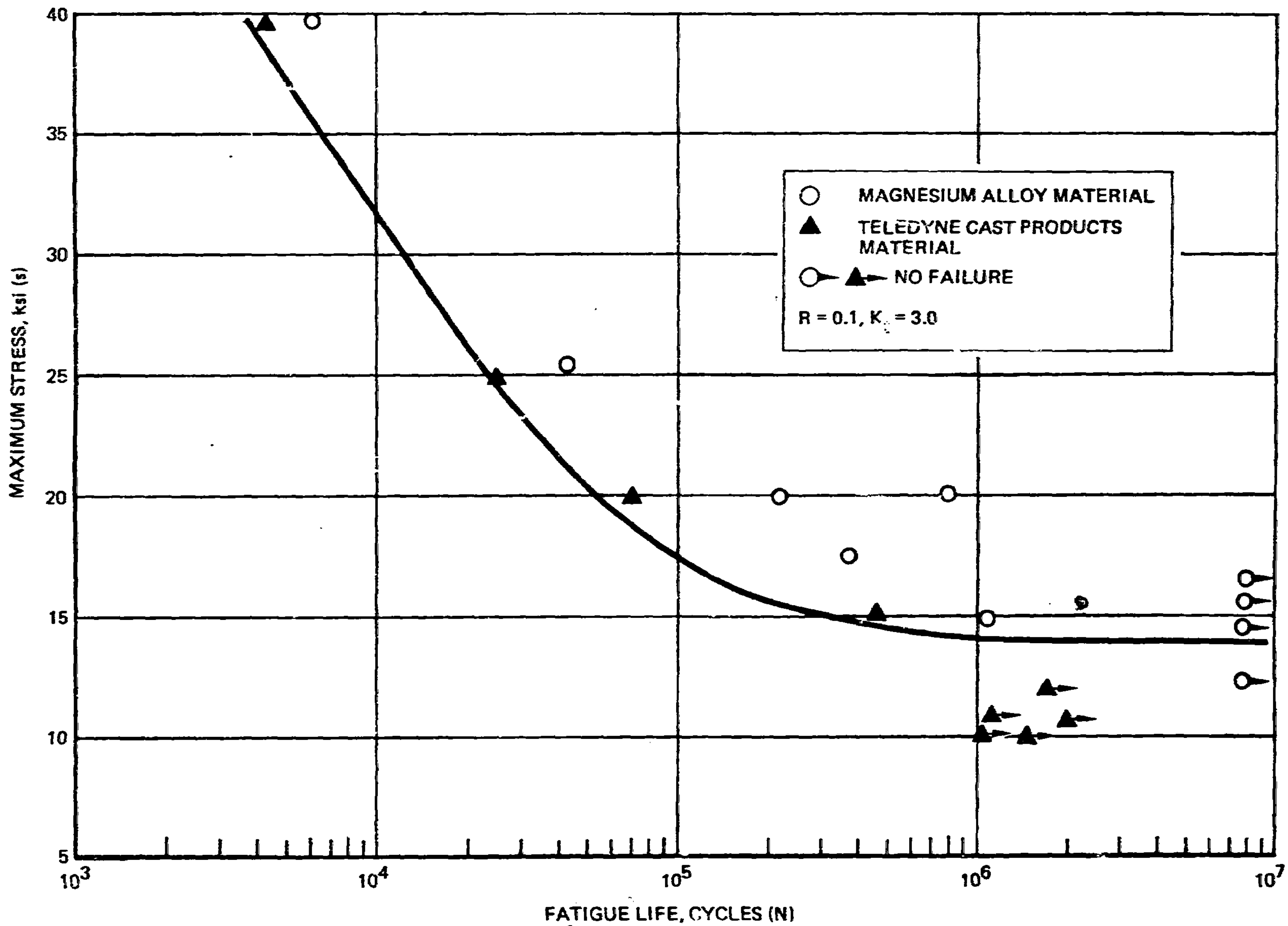


FIGURE 101. S/N PLOT OF NOTCHED FATIGUE PROPERTIES OF A357-T6

(i) Crack Growth Properties

Five crack growth specimens were excised from the designated area of five step plate castings produced by two foundries and forwarded to the AFWAL Materials Laboratory for testing. The crack growth rates of material from each foundry were found to be similar. A full report of the testing and results was prepared by Jon D. Tirpak, 2Lt, USAF. The text of this report is included in the Appendixes F and G. The results are summarized in Figures 101 and 102.

(2) A201 Alloy

(a) Tensile Properties

The tensile test results of specimens excised from step plates are listed in Tables 38, 39, 40 and 41. The following summarizes these results:

	Smithford Products Company			Morris Bean and Company		
	TUS (ksi)	TYS (ksi)	e (%)	TUS (ksi)	TYS (ksi)	e (%)
Designated Area:						
Average	64.0	58.0	6	65.8	60.2	6
Minimum	59.9	53.7	2	62.8	56.2	2
Maximum	69.0	62.7	11	69.6	63.4	9
Non-designated Area:						
Average	60.5	55.3	4	65.4	61.2	3
Minimum	55.4	50.7	3	62.9	57.7	1
Maximum	66.6	58.1	8	67.6	63.6	9

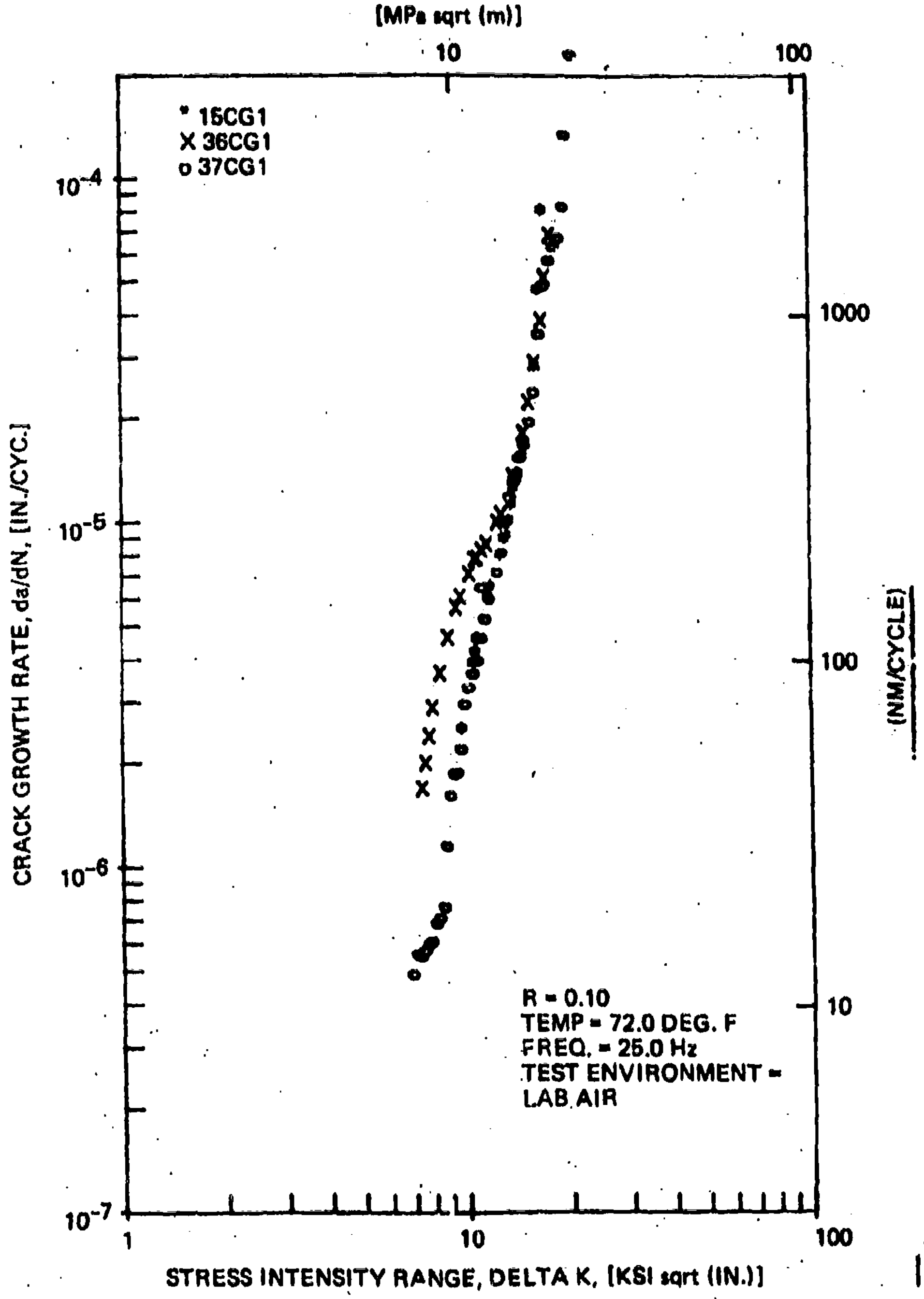


FIGURE 103. MAGNESIUM ALLOY PRODUCTS (A357) CRACK GROWTH TEST RESULTS

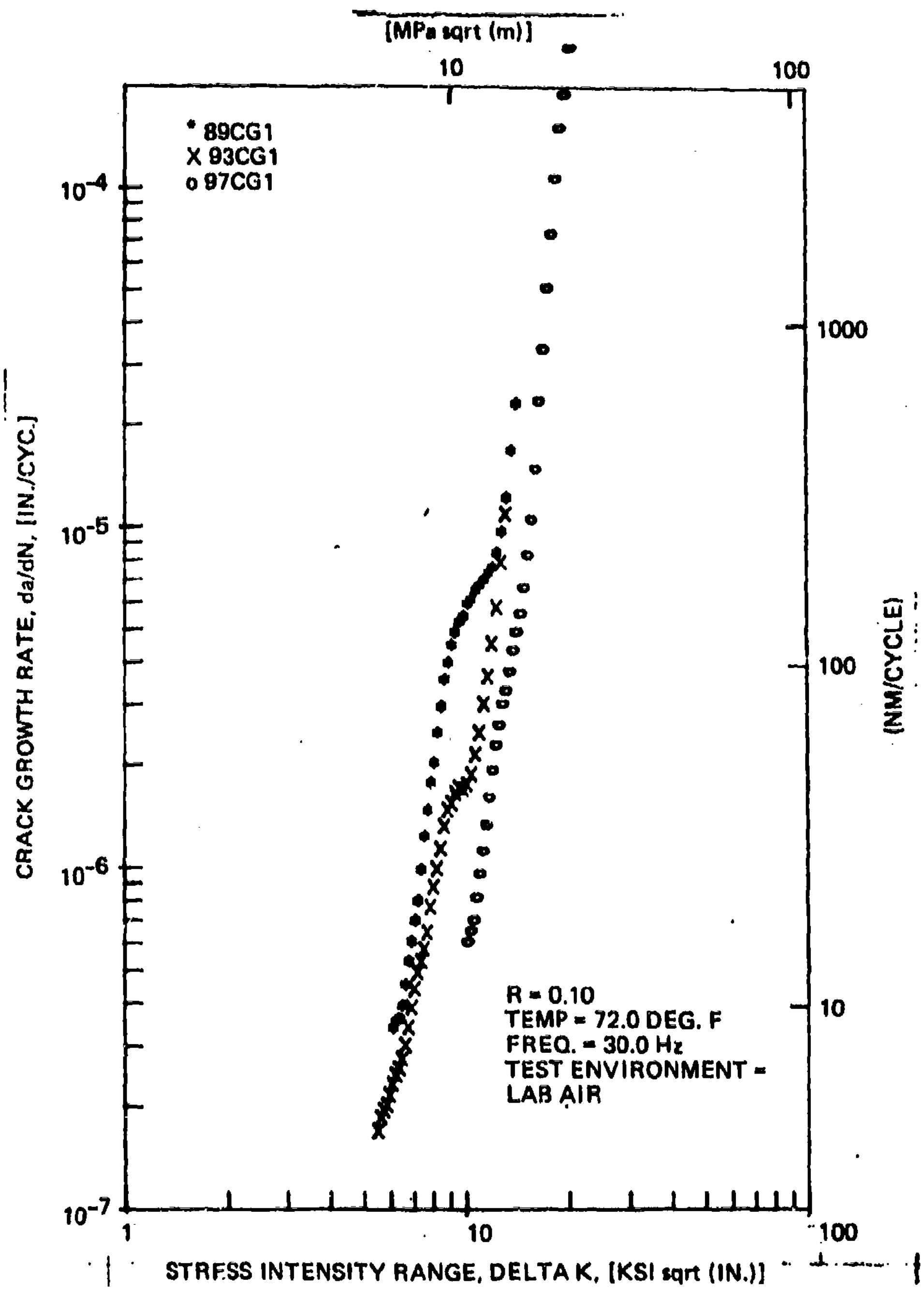


FIGURE 102. TELEDYNE CAST PRODUCTS (A357) CRACK GROWTH TEST RESULTS

TABLE 38. ROOM TEMPERATURE TENSILE PROPERTIES, DESIGNATED AREA, SMITHFORD PRODUCTS, A201 ALLOY

Item No.	Test Specimen Identification	TUS (ksi)	TYS (ksi)	e (%)
1	A101-T1	60.7	55.0	8
2	-T2	66.5	60.5	6
3	-T3	68.9	62.6	5
4	-T4	60.9	55.0	7
5	A104-T1	60.4	54.5	8
6	-T2	65.5	59.0	6
7	-T3	59.9	53.8	7
8	-T4	68.8	62.7	5
9	A107-T1	60.6	54.6	8
10	-T2	65.9	59.8	6
11	-T3	60.7	54.4	7
12	-T4	68.5	62.6	5
13	A110-T1	59.9	53.9	8
14	-T2	65.5	59.2	6
15	-T3	60.5	54.6	7
16	-T4	69.0	63.1	5
17	A113-T1	63.1	57.0	5
18	-T2	66.3	60.9	4
19	-T3	63.5	57.4	6
20	-T4	65.6	62.0	2
21	A106-T1	62.6	57.0	5
22	B102-T1	62.8	57.4	5
23	-T2	67.1	60.9	5
24	-T3	62.2	56.8	6
25	-T4	67.2	62.6	3
26	B105-T1	62.6	56.2	6
27	-T2	66.3	59.4	6
28	-T3	62.7	56.0	6
29	-T4	65.9	60.6	4
30	B108-T1	63.3	57.4	6
31	-T2	66.5	60.6	5
32	-T3	63.1	57.2	6
33	-T4	65.4	62.4	2
34	B111-T1	63.2	56.7	6
35	-T2	66.9	61.4	5
36	-T3	62.8	56.6	5
37	-T4	67.0	62.4	2
38	B114-T1	62.6	55.4	6
39	-T2	67.2	60.8	6
40	-T3	62.9	56.2	6
41	-T4	65.5	61.1	3
42	B109-T1	62.7	56.0	7
43	H103	66.3	60.1	5
44	H112	67.1	60.6	5
45	H115	60 1	54.3	6
46	D119-T1	61.1	53.7	11

TABLE 38. ROOM TEMPERATURE TENSILE PROPERTIES, DESIGNATED AREA, SMITHFORD PRODUCTS, A201 ALLOY (Concluded)

Item No.	Test Specimen Identification	TUS (ksi)	TYS (ksi)	e (%)
47	D120-T1	61.3	54.5	10
48	D121-T1	61.1	54.1	11
49	C111-T1	60.6	59.0	8
50	G123-T1	60.6	54.1	9
51	G124-T1	60.0	53.7	10

TABLE 39. ROOM TEMPERATURE TENSILE PROPERTIES, NON-DESIGNATED AREA, SMITHFORD PRODUCTS, A201 ALLOY

Item No.	Test Specimen Identification	TUS (ksi)	TYS (ksi)	e (%)
1	F101-T6	58.0	53.4	5
2	-T7	58.2	52.9	6
3	-T8	62.9	56.8	7
4	F104-T6	56.1	51.1	5
5	-T7	58.3	53.0	5
6	-T8	63.9	58.1	6
7	F107-T6	56.3	51.1	5
8	-T7	56.0	51.2	5
9	-T8	64.8	58.1	8
10	F110-T6	55.4	50.7	5
11	-T7	56.8	51.9	4
12	-T8	65.6	59.6	7
13	F113-T6	59.5	55.4	3
14	-T7	60.7	55.8	4
15	-T8	66.6	58.8	7
16	F106-T6	62.9	57.4	5
17	F102-T6	60.3	55.6	4
18	-T7	61.4	57.3	4
19	F105-T6	61.3	55.8	4
20	-T7	62.1	56.0	5
21	F108-T6	61.1	56.6	3
22	-T7	61.6	56.8	4
23	F111-T6	62.1	57.2	4
24	F111-T7	61.1	56.1	4
25	F114-T6	60.7	55.6	4
26	-T7	61.3	56.0	3
27	F109-T6	59.1	54.8	3
28	F103-T6	60.6	55.4	3
29	-T7	60.1	55.0	4
30	F112-T6	60.3	55.7	3
31	-T7	60.8	56.0	4
32	F115-T6	58.4	53.1	5

TABLE 40. ROOM TEMPERATURE TENSILE PROPERTIES, DESIGNATED AREA, MORRIS BEAN AND COMPANY, A201 ALLOY

Item No.	Test Specimen Identification	TUS (ksi)	TYS (ksi)	e (%)
1	A201-T1	63.9	61.5	3
2	-T2	65.9	60.0	6
3	-T3	65.7	59.9	5
4	-T4	68.5	63.4	5
5	B202-T1	65 2	58.8	6
6	-T2	63.6	56.4	9
7	-T3	63.9	57.4	5
8	-T4	66.5	59.2	8
9	H203-T1	65.6	59.4	8
10	A204-T1	65.9	59.9	5
11	-T2	67.0	60.4	8
12	-T3	65.4	59.9	5
13	-T4	67.2	60.8	9
14	B205-T1	65.1	61.9	4
15	-T2	65.6	60.1	5
16	-T3	66.5	60.5	4
17	-T4	69.6	63.2	7
18	A206-T1	64.9	61.5	4
19	A207-T1	64.2	60.7	4
20	-T2	66.1	59.7	6
21	-T3	64.8	60.2	3
22	-T4	67.2	60.8	8
23	B208-T1	63.8	61.1	4
24	-T2	63.8	57.7	7
25	-T3	62.8	58.3	3
26	-T4	67.2	60.2	8
27	B209-T1	65.0	63.1	3
28	A210-T1	64.6	62.0	2
29	-T2	67.3	60.0	5
30	-T3	64.8	60.0	4
31	-T4	69.3	62.7	8
32	B211-T1	65.7	58.9	6
33	-T2	66.6	58.4	8
34	-T3	65.7	62.2	6
35	-T4	67.5	60.4	9
36	H212-T1	66.9	60.7	6
37	A213-T1	66.3	60.4	4
38	-T2	67.7	61.1	7
39	-T3	66.4	60.1	5
40	-T4	62.9	56.2	7
41	B214-T1	64.0	59.3	3
42	-T2	64.5	58.9	6
43	-T3	64.7	60.3	4
44	-T4	67.8	63.1	8
45	H215-T1	66.1	59.6	6
46	D219-T1	64.6	59.8	5

TABLE 40. ROOM TEMPERATURE TENSILE PROPERTIES, DESIGNATED AREA, MORRIS BEAN AND COMPANY, A201 ALLOY (Concluded)

Item No.	Test Specimen Identification	TUS (ksi)	TYS (ksi)	e (%)
47	D220-T1	64.9	58.9	7
48	D221-T1	65.6	60.3	5
49	C222-T1	68.1	61.3	7
50	G223-T1	64.4	59.8	5
51	G224-T1	65.2	60.8	5
52	H225-T1	67.5	60.9	8

TABLE 41. ROOM TEMPERATURE TENSILE PROPERTIES, NON-DESIGNATED AREA, MORRIS BEAN AND COMPANY, A201 ALLOY

Item No.	Test Specimen Identification	TUS (ksi)	TYS (ksi)	e (%)
1	F201-T6	65.5	61.7	4
2	-T7	63.9	61.7	1
3	-T8	66.0	57.7	7
4	F202-T6	65.9	59.4	5
5	-T7	64.7	58.1	5
6	F203-T6	67.4	63.6	3
7	-T7	67.6	60.3	3
8	F204-T6	63.0	61.2	2
9	-T7	67.2	61.8	5
10	-T8	67.3	60.7	8
11	F205-T6	66.4	63.0	4
12	-T7	64.3	61.8	2
13	F206-T6	66.8	61.9	2
14	F207-T6	65.2	62.0	3
15	-T7	65.5	61.5	3
16	-T8	67.2	60.3	8
17	F208-T6	66.0	61.5	4
18	-T7	63.3	60.3	2
19	F209-T6	67.4	62.0	3
20	F210-T6	64.5	62.0	3
21	-T7	64.9	62.0	2
22	-T8	66.9	59.3	9
23	F211-T6	65.2	61.8	3
24	-T7	64.9	60.8	4
25	F212-T6	64.3	62.8	2
26	-T7	67.3	62.4	4
27	F213-T6	65.1	61.8	3
28	-T7	65.6	61.7	3
29	-T8	62.5	59.7	6
30	F214-T6	65.7	63.0	2
31	-T7	62.9	61.0	2
32	F215-T6	65.5	62.0	2
33	F225-T6	63.6	59.6	5

(b) Compression, Bearing, and Shear Properties

Compression Shear Strength: Test values for each compression specimen are listed in Tables 42, 43, 44 and 45. Average compression yield strength values were as follows:

	Designated Area CYS (ksi)	Non-designated Area CYS (ksi)
Smithford Products Company	64.7	55.3
Morris Bean and Company	64.1	58.9
Combined	64.4	57.1

Shear Strength: Shear strength test results are listed in Tables 42, 43, 44 and 45. Average shear ultimate strength values were as follows:

	Designated Area SUS (ksi)	Non-designated Area SUS (ksi)
Morris Bean and Company	40.2	39.4
Smithford Products Company	41.0	38.8
Combined	40.6	39.1

Bearing Properties: Bearing property test results with e/D ratios of 1.5 and 2.0 are shown in Tables 42, 43, 44 and 45. The average bearing ultimate and yield strength values were as follows:

	Designated Area				Non-designated Area			
	e/D Ratio 1.5		e/D Ratio 2.0		e/D Ratio 1.5		e/D Ratio 2.0	
	BUS (ksi)	BYS (ksi)	BUS (ksi)	BYS (ksi)	BUS (ksi)	BYS (ksi)	BUS (ksi)	BYS (ksi)
Smithford Products Company	99.5	88.7	136.9	111.1	107.4	87.8	127.5	99.2
Morris Bean and Company	110.0	93.7	142.4	112.6	108.4	90.4	129.7	104.4
Combined	104.8	91.2	139.6	111.8	107.9	89.1	128.6	101.8

TABLE 42. COMPRESSION, SHEAR, AND BEARING PROPERTIES OF A201 STEP PLATES SMITHFORD PRODUCTS, DESIGNATED AREA

Compression Yield Strength (CYS)

Item No.	Specimen Identification	CYS (ksi)	Ultimate and Yield Strength of Companion Tensile Specimen TYS (ksi)	Identification
1	A101-C1	64.7	55.0	A104-T4
2	A104-C1	65.3	62.7	A104-T4
3	A107-C1	64.8	62.6	A107-T4
4	A110-C1	65.5	53.1	A110-T4
5	A113-C1	63.4	62.0	A113-T4

Shear Ultimate Strength (SUS)

Item No.	Specimen Identification	SUS (ksi)	TUS (ksi)	
1	A101-S1	41.0	60.9	A101-T4
2	A104-S1	41.3	68.8	A104-T4
3	A107-S1	41.2	68.5	A107-T4
4	A110-S1	41.2	69.0	A110-T4
5	A113-S1	40.1	65.6	A113-T4

Bearing Yield and Ultimate Strength Properties (BYS and BUS)

Item No.	Specimen Identification	BYS (ksi)	BUS (ksi)	TYS (ksi)	TUS (ksi)	
		e/D = 1.5				
1	B102-B1	89.9	95.2	62.6	67.2	B102-T4
2	B105-BI	88.1	98.7	60.6	65.9	B105-T4
3	B108-B1	90.1	100.9	62.4	65.4	B108-T4
4	B111-B1	88.6	99.1	62.4	67.0	B111-T4
5	B114-B1	86.7	103.6	61.1	65.5	B114-T4
		e/D = 2.0				
1	A101-B1	131.4	134.6	55.0	60.9	B101-T4
2	A104-B1	107.0	136.1	62.7	68.8	B101-T4
3	A107-B1	107.0	139.6	62.6	68.5	B107-T4
4	A110-B1	103.8	137.9	63.1	69.0	A110-T4
5	A113-B1	106.3	136.2	62.0	65.6	A113-T4

TABLE 43. COMPRESSION, SHEAR, AND BEARING PROPERTIES OF A201 STEP PLATES, SMITHFORD PRODUCTS, NON-DESIGNATED AREA

Compression Yield Strength (CYS)

Item No.	Specimen Identification	CYS (ksi)	Ultimate and Yield Strength of Companion Tensile Specimen TYS (ksi)	Identification
1	F101-C2	55.3	53.4	F101-T6
2	F104-C2	54.5	51.1	F104-T6
3	F107-C2	54.8	51.1	F107-T6
4	F110-C2	55.1	50.7	F110-T6
5	F113-C2	57.0	55.4	F113-T6

Shear Ultimate Strength (Sus)

Item No.	Specimen Identification	SUS (ksi)	TUS (ksi)	
1	F101-S2	39.9	58.2	F101-T7
2	F104-S2	39.5	58.3	F104-T7
3	F107-S2	37.2	56.0	F107-T7
4	F110-S2	39.4	56.8	F110-T7
5	F113-S2	37.9	60.7	F113-T7

Bearing Yield and Ultimate Strength Properties (BYS and BUS)

Item No.	Specimen Identification	BYS (ksi)	BUS (ksi)	TYS (ksi)	TUS (ksi)	
		e/D = 1.5				
1	F101-B2	87.1	106.1	56.8	62.9	F101-T8
2	F104-B2	88.2	107.3	58.1	63.9	F104-T8
3	F107-B2	88.2	108.7	58.1	64.8	F107-T8
4	F110-B2	88.2	107.5	59.6	65.6	F110-T8
5	F113-B2	87.3	107.3	58.8	66.6	F113-T8
		e/D = 2.0				
1	F101-B3	98.8	125.5	52.9	58.2	F101-T7
2	F104-B3	97.4	126.5	53.0	58.3	F101-T7
3	F107-B3	100.0	129.7	51.2	56.0	F107-T7
4	F110-B3	98.1	125.9	51.9	56.8	F110-T7
5	F113-B3	101.9	129.2	55.8	60.7	F113-T7

TABLE 44. COMPRESSION, SHEAR, AND BEARING PROPERTIES OF A201 STEP PLATES, MORRIS BEAN AND COMPANY, DESIGNATED AREA

Compression Yield Strength (CYS)

Item No.	Specimen Identification	CYS (ksi)	TYS (ksi)	Identification
			Ultimate and Yield Strength of Companion Tensile Specimen	
1	A201-C1	62.0	63.4	A201-T4
2	A204-C1	63.5	60.8	A204-T4
3	A207-C1	64.0	60.8	A207-T4
4	A210-C1	64.2	62.7	A210-T4
5	A213-C1	63.0	56.2	A213-T4

Shear Ultimate Strength (SUS)

Item No.	Specimen Identification	SUS (ksi)	TUS (ksi)	
1	A201-S1	40.1	68.5	A201-T4
2	A204-S1	40.4	67.2	A204-T4
3	A207-S1	39.9	67.2	A207-T4
4	A210-S1	40.0	69.3	A210-T4
5	A213-S1	40.7	62.9	A113-T4

Bearing Yield and Ultimate Strength Properties (BYS and BUS)

Item No.	Specimen Identification	BYS (ksi)	BUS (ksi)	TYS (ksi)	TUS (ksi)	
		e/D = 1.5				
1	B202-B1	91.3	111.1	59.2	66.5	B202-T4
2	B205-B1	95.2	111.4	63.2	69.6	B205-T4
3	B208-B1	92.9	110.6	60.2	67.2	B208-T4
4	B211-B1	93.8	110.2	60.4	67.5	B211-T4
5	B214-B1	95.2	111.4	63.1	67.8	B214-T4
		e/D = 2.0				
1	A201-B1	106.1	139.1	63.4	68.5	A201-T1
2	A204-B1	113.8	140.6	60.8	67.2	A204-T1
3	A207-B1	110.8	143.6	60.8	67.2	A207-T1
4	A210-B1	226.9	145.5	62.7	69.3	A210-T1
5	A213-B1	115.4	143.0	56.2	62.9	A213-T1

TABLE 45. COMPRESSION, SHEAR, AND BEARING PROPERTIES OF A201 STEP PLATES, MORRIS BEAN AND COMPANY, NON-DESIGNATED AREA

Compression Yield Strength (CYS)

Item No.	Specimen Identification	CYS (ksi)	Ultimate and Yield Strength of Companion Tensile Specimen: TYS (ksi)	Ultimate and Yield Strength of Companion Tensile Specimen: Identification
1	F201-C2	61.6	61.7	F201-T6
2	F204-C2	61.7	61.2	F204-T6
3	F207-C2	63.8	62.0	F207-T6
4	F210-C2	62.8	62.0	F210-T6
5	F213-C2	62.6	61.8	F213-T6

Shear Ultimate Strength (SUS)

Item No.	Specimen Identification	SUS (ksi)	TUS (ksi)	
1	F201-S2	39.6	63.9	F201-T7
2	F204-S2	39.0	67.2	F204-T7
3	F207-S2	39.7	65.5	F207-T7
4	F210-S2	39.9	64.9	F210-T7
5	F213-S2	38.7	65.6	F213-T7

Bearing Yield and Ultimate Strength Properties (BYS and BUS)

Item No.	Specimen Identification	BYS (ksi)	BUS (ksi)	TYS (ksi)	TUS (ksi)	
		e/D = 1.5				
1	F201-B2	89.1	107.2	57.7	66.0	F201-T8
2	F204-B2	92.8	109.9	60.7	67.3	F204-T8
3	F207-B2	89.3	107.3	60.3	67.2	F207-T8
4	F210-B2	90.4	108.4	59.3	66.9	F210-T8
5	F213-B2	90.1	109.4	59.7	62.5	F213-T8
		e/D = 2.0				
1	F201-B3	105.2	105.2	61.7	63.9	F201-T7
2	F204-B3	103.0	123.6	61.8	67.2	F204-T7
3	F207-B3	105.0	136.5	61.5	65.5	F207-T7
4	F210-B3	103.0	130.3	62.1	64.9	F210-T7
5	F213-B3	105.7	129.3	61.7	65.6	F213-T7

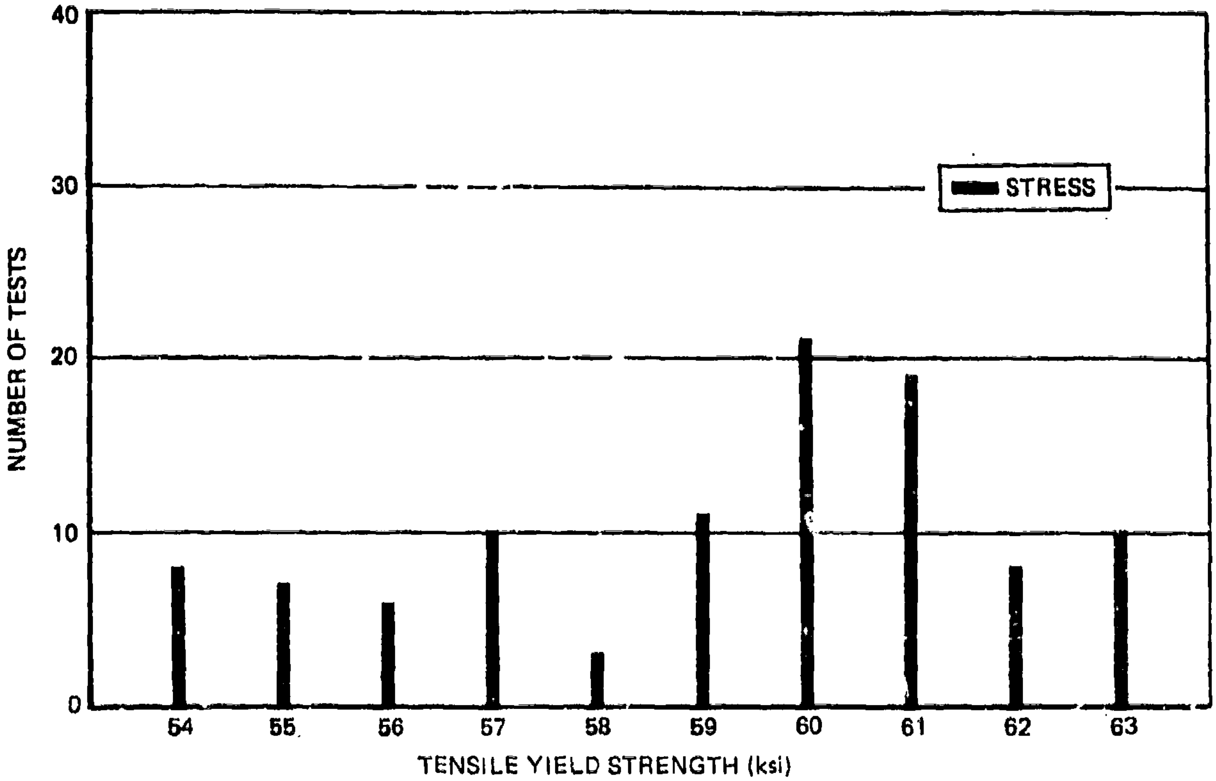
(c) Design Property Determination

Tensile Properties

Although all the tensile values from the designated area of the step plates exceeded the minimum target values of 60 ksi UTS and 53 ksi YS, the distribution of the values were skewed. This prevented the data from being combined into a single population for determining A and B design allowables. The property variation between the two groups of data is shown in Figure 103. The data were analyzed by Battelle Columbus Laboratories. The complete report of their findings is included in the Appendix D. A separate analysis was made of data from the material produced by each foundry. Although the data provided were insufficient for MIL-HDBK-5 A and B allowable determinations, the analysis did provide information for guidance in determining specification S values. The results were as follows:

Foundry and Property Basis (1)	Designated Area		Non-Designated Area	
	Fbu (ksi)	Fby (ksi)	Ftu (ksi)	Fty (ksi)
Smithford Products Company				
A values	-	-	52	48
B values	60[a]	53[1]	55	51
Morris Bean and Company				
A values	61	56	61	57
B values	63	57	63	58

NOTE: 1. Determined by non-parametric technique



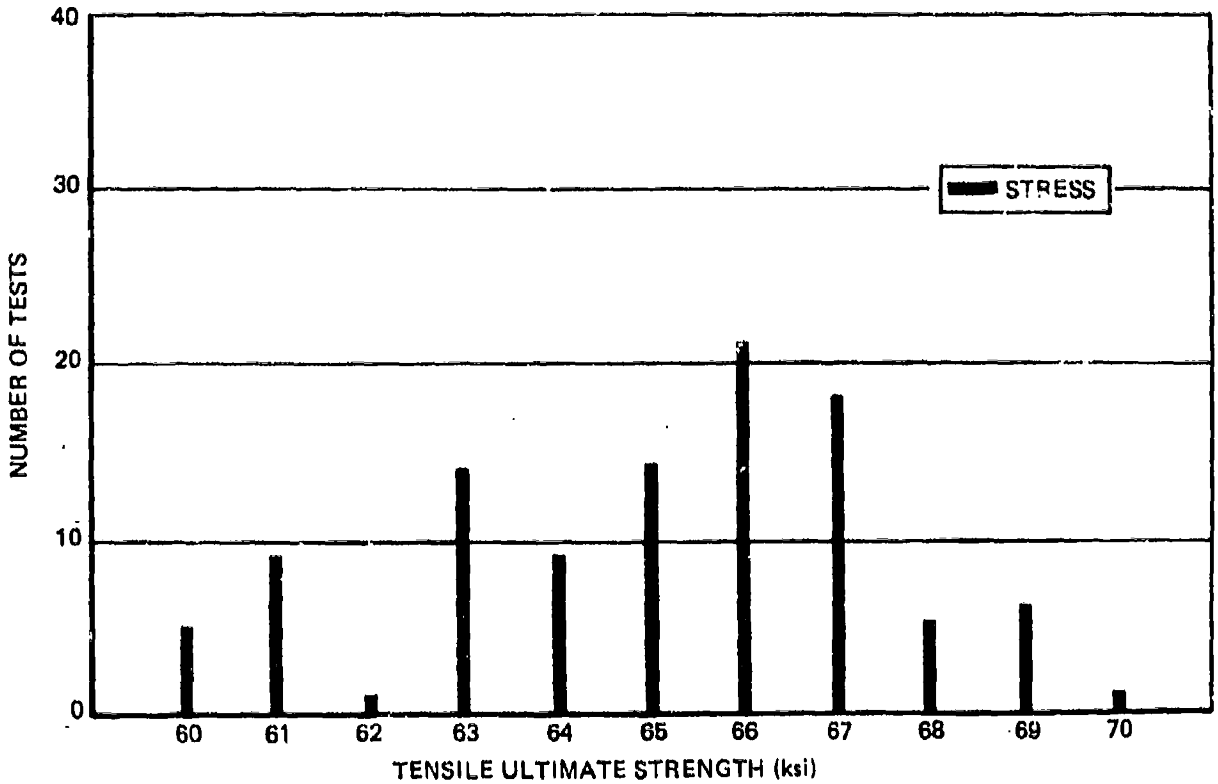


FIGURE 104 HISTOGRAMS FOR A201-T7 TENSILE YIELD AND ULTIMATE STRENGTH DATA, DESIGNATED AREA OF STEP PLATE

Compression, Shear, and Bearing Property Ratio

A tensile test was performed in each test area for comparison with compression, bearing, and shear property values to establish a property ratio. The average ratio of properties from each area was as follows:

Property Ratio	e/D Ratio	Smithford Products Co. Designated Area 0.500 inch	Smithford Products Co. Non-Designated Area 0.750 inch	Morris Bean and Company Designated Area 0.500 inch	Morris Bean and Company Non-Designated Area 0.750 inch
CYS/TYS		1.034	1.058	1.044	1.012
SUS/TUS		0.603	0.669	0.601	0.602
BUS/TUS	1.5	1.504	1.659	1.639	1.645
BYS/TYS	1.5	1.435	1.507	1.531	1.518
BUS/TUS	2.0	2.023	2.200	2.127	1.983
BYS/TYS	2.0	1.694	1.875	1.857	1.690

The following reduced values were obtained after combining the non-designated and designated area results:

Property Ratio	e/D Ratio	Smithford Products Company	Morris Bean and Company
CYS/TYS		1.034	1.005
SUS/TUS		0.615	0.589
BUS/TUS	1.5	1.526	1.616
BYS/TYS	1.5	1.446	1.511
BUS/TUS	2.0	2.053	1.989
BYS/TYS	2.0	1.730	1.700

The following property ratios were determined by combining the values of each property ratio from each process.

Property Ratio	e/D Ratio	Combined Ratio Values
CYS/TYS		1.024
SUS/TUS		0.605
BUS/TUS	1.5	1.581
BYS/TYS	1.5	1.481
BUS/TUS	2.0	2.041
BYS/TYS	2.0	1.738

(d) Proposed Specification Values

The proposed specification values for A201-T7 castings are as follows:

Minimum Properties	Designated Area	Non-Designated Area
Ultimate	60 ksi	56 ksi
Tensile Strength		
Yield Strength	50 ksi	48 ksi
Elongation	3%	2%

A review of the tensile data shows that the proposed minimum strength values were met or exceeded in each of the tests except for one UTS of 55.4 ksi in a non-designated area. The three-percent elongation value was achieved in 98 of the 102 tests, while the two-percent elongation in the non-designated area tests was achieved 54 of the 55 tests.

(e) Design Property Table

The design property information shown in Table 35 was developed from the proposed specification tensile values and related ratio values of compression, shear, and bearing.

(f) Elevated Temperature Tensile Properties

The results of elevated temperature tensile testing at 250, 300, and 400F are listed in Tables 36 and 37. The tensile properties at the various temperatures are compared in Figure 110. The figure depicts a decrease of ultimate and yield strength values but no significant change with an increase of temperature.

TABLE 46. PROPOSED MIL-HDBK-5 TABLE FOR DESIGN MECHANICAL AND PHYSICAL PROPERTIES OF A201.0 ALUMINUM ALLOY CASTING

Specification	(Proposed AMS-XXX)	
Form	Casting	
Condition	T7	
Thickness, in.	0.500	
Location	Designated Area	Non-designated Area
Basis	S	S
Mechanical properties:		
F_{tu}, ksi	60	56
F_{ty}, ksi	50	48
F_{cy}, ksi	51	49
F_{su}, ksi	36	34
F_{bru}, ksi:		
(e/D = 1.5)	95	88
(e/D = 2.0)	122	114
F_{bry}, ksi:		
(e/D = 1.5)	74	71
(e/D = 2.0)	87	83
e, per cent	3	2
E, 10^3 ksi	10.3	
E_c, 10^3 ksi	10.7	
G, 10^3 ksi	4.0	
	0.33	
Physical properties:		
, lb/in.^{3}	0.101	
C, Btu/(lb)(F)	0.22 (at 212F)	
K, Btu/[(hr)(ft^2((F)/ft]	70 (at 77F)	

Table 47. ELEVATED TEMPERATURE TENSILE PROPERTIES, SMITHFORD PRODUCTS, A201 ALLOY

Specimen Identification	Test Temperature, F	Tensile Properties TUS ksi	TYS ksi	e (%)
101T5	250	59.1	54.9	11
102T5	250	58.9	54.8	7
104T5	250	59.9	54.6	10
105T5	300	55.4	51.5	9
107T5	300	56.1	53.1	10
108T5	350	52.5	49.0	10
110T5	350	52.9	49.5	10
111T5	350	53.1	48.8	9
113T5	400	46.4	42.8	8
114T5	400	47.1	42.3	10

Table 48. ELEVATED TEMPERATURE TENSILE PROPERTIES, MORRIS BEAN AND CO., A201 ALLOY

Specimen Identification	Test Temperature, F	Tensile Properties TUS ksi	TYS ksi	e (%)
201T5	250	59.6	54.8	10
202T5	250	56.6	51.5	12
204T5	300	56.3	54.4	10
205T5	300	55.4	52.1	8
207T5	300	55.4	51.9	9
208T5	350	49.2	46.4	11
210T5	350	51.0	47.6	10
211T5	400	44.4	41.4	12
213T5	400	46.0	42.2	10
214T5	400	45.8	42.6	9

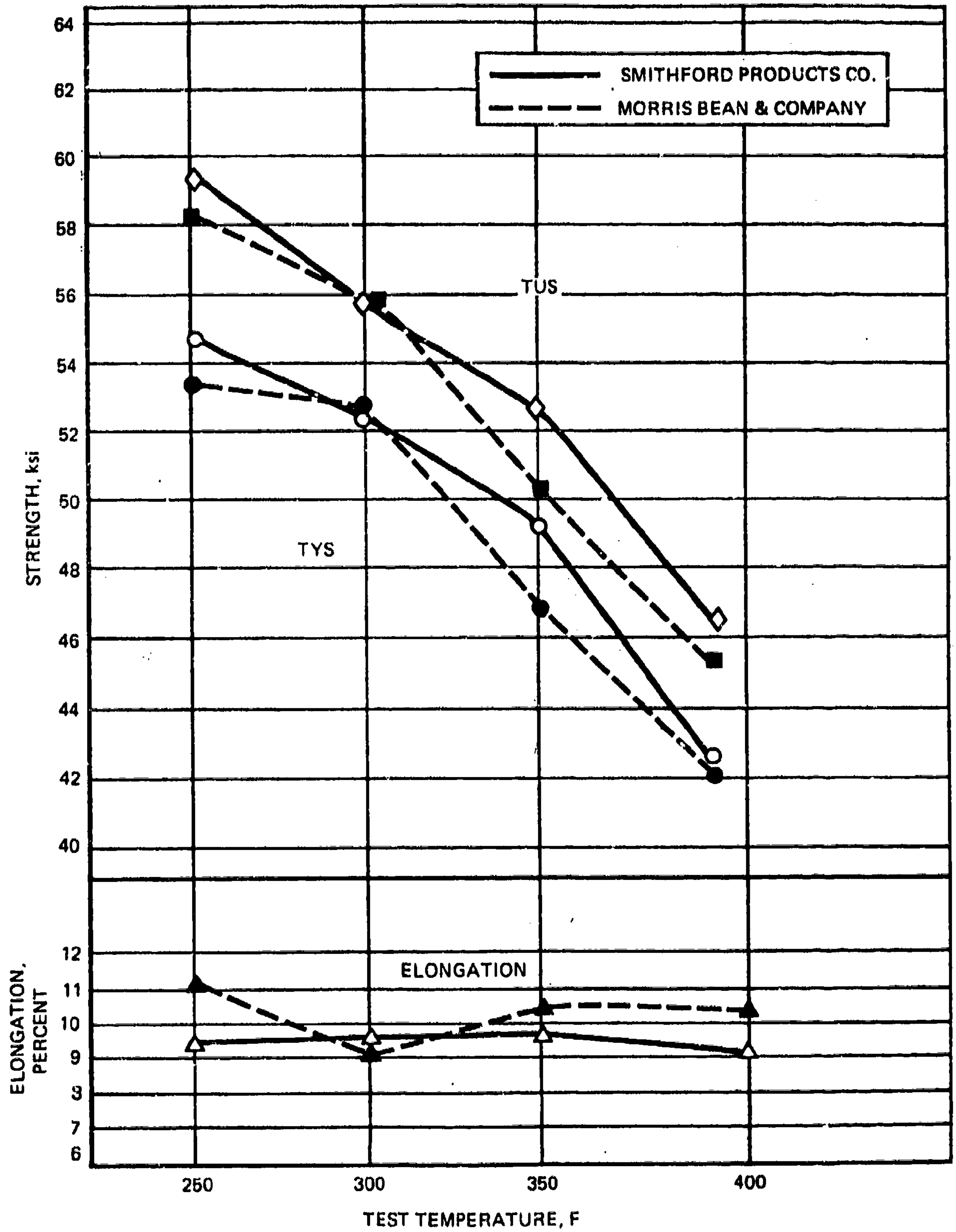


FIGURE 105. EFFECT OF TEMPERATURE ON TENSILE PROPERTIES OF A201-T7 MATERIAL

(g) Fracture Toughness Properties

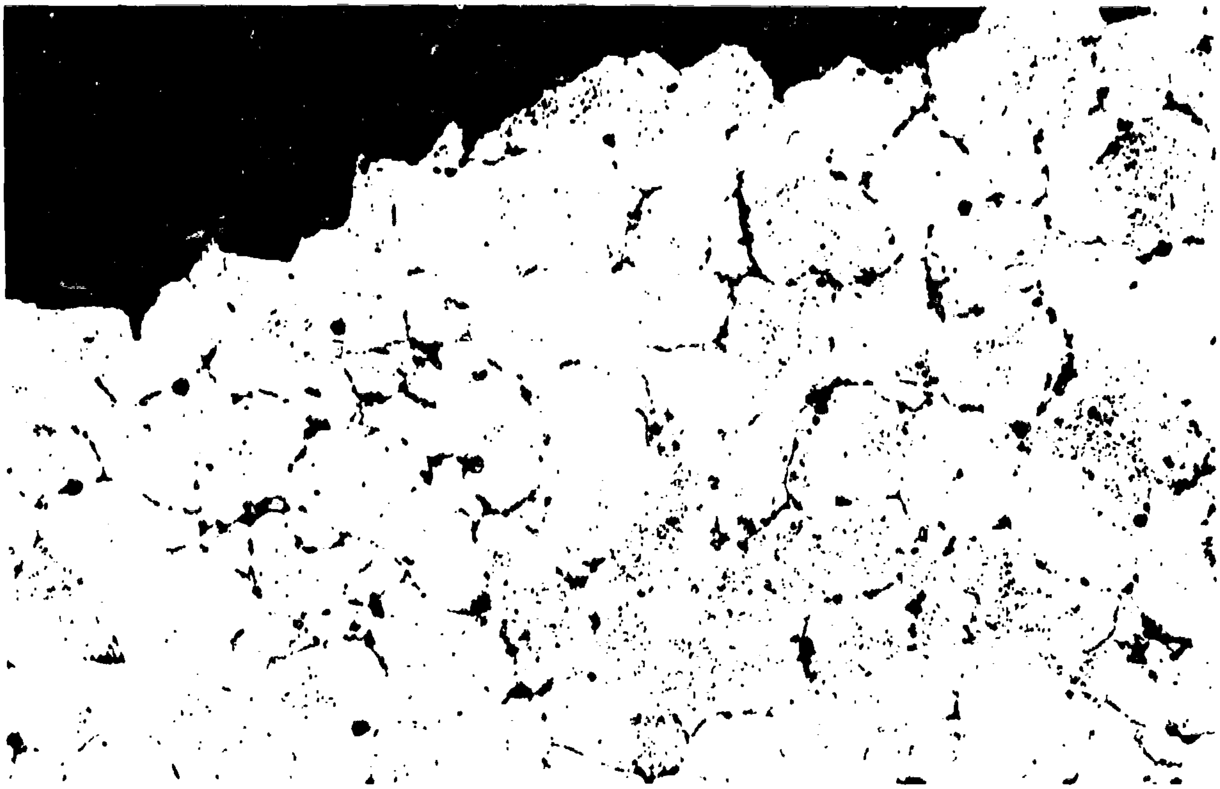
Fracture toughness values obtained from specimens machined from separately cast test blocks were as follows:

Specimen	Yield Strength (ksi)	Fracture Toughness (ksi in)	Reason Not Valid	Producing Foundry
128P	63.2	23.2	Valid K_{Ic}	Smithford Products Co.
128A	59.4	24.9	"	Smithford Products Co.
S/N 20	54.8	33.2	"	Morris Bean and Co.
S/N 30-1	60.1	30.7	"	Morris Bean and Co.
S/N 32-1	59.2	32.8	"	Morris Bean and Co.
Average	59.3	29.9		

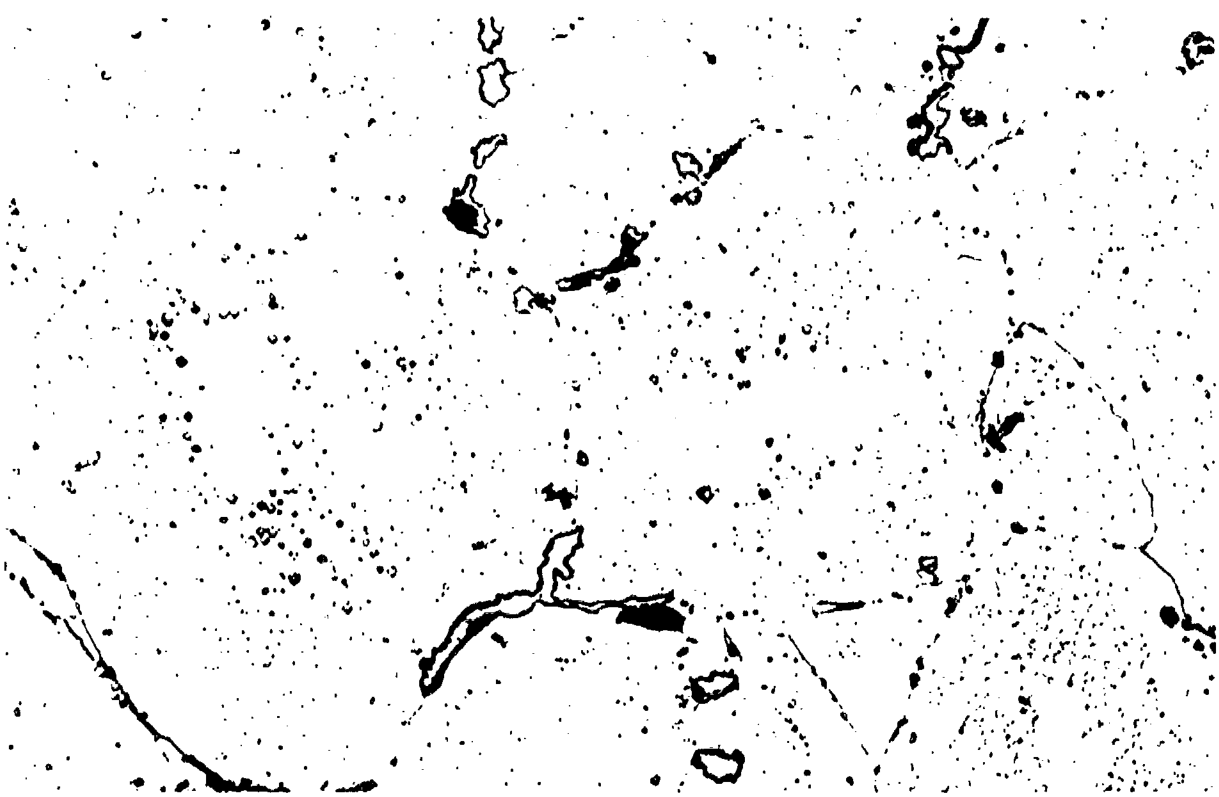
The microstructure of specimens exhibiting the highest and lowest values was evaluated in an attempt to determine a reason for the variation. Photomicrographs from specimen 128P (23.2 ksi $in^{1/2}$) and specimen 32-1 (32.8 ksi $in^{1/2}$) are shown in Figures 106 and 107. The microstructure of the lower toughness specimen showed a greater amount of precipatate, both inter- and intragranular. Since failure occurred intergranularly, the lower fracture toughness was attributed to the greater amount of grain boundry precipitate in the microstructure of specimen 128P. The effect of welding on the toughness properties is discussed later in the report.

(h) Notched Fatigue Properties

The endurance of notched fatigue specimens tested at various stress levels was plotted in Figure 108. The apparent endurance stress limit of material from both foundries was between 6 and 10 ksi at 10^7 cycles. The effect of radiographic unsoundness and weld repair is discussed later in the report.

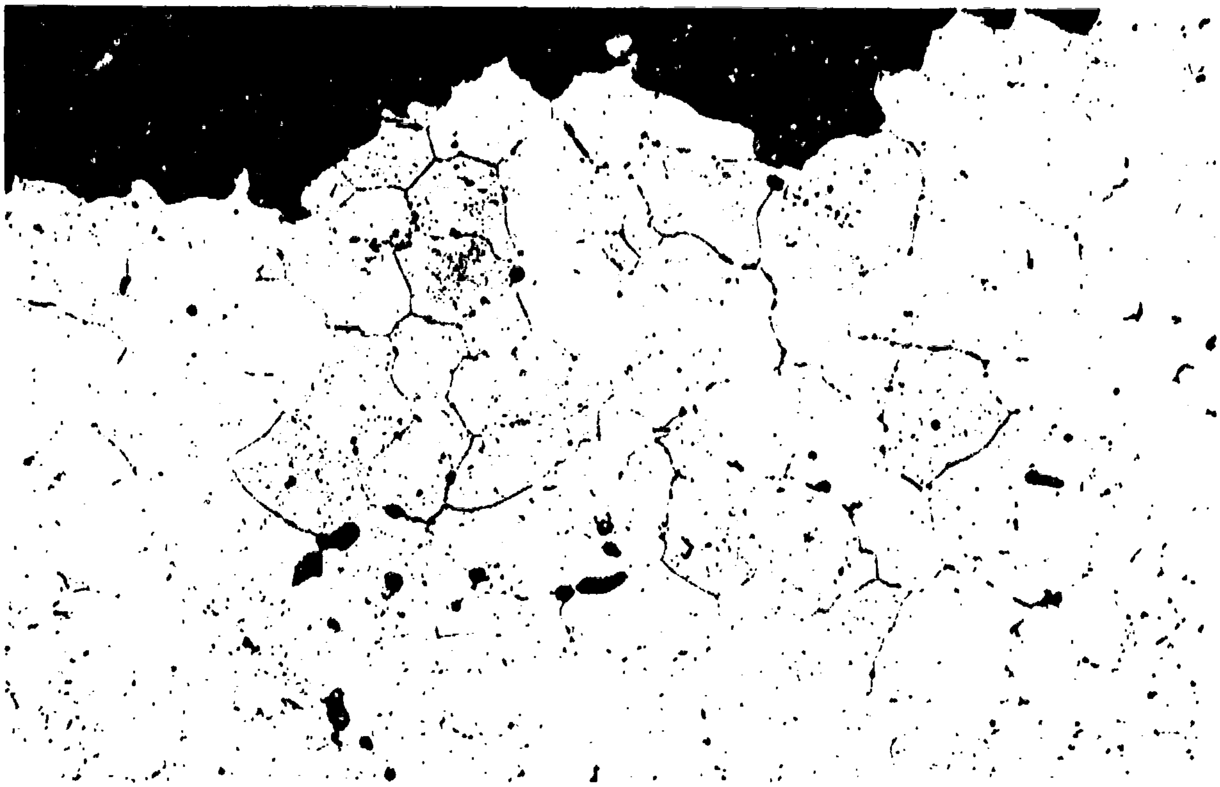


(KELLER'S ETCH) X100 SPECIMEN 128P 85-00239-20A

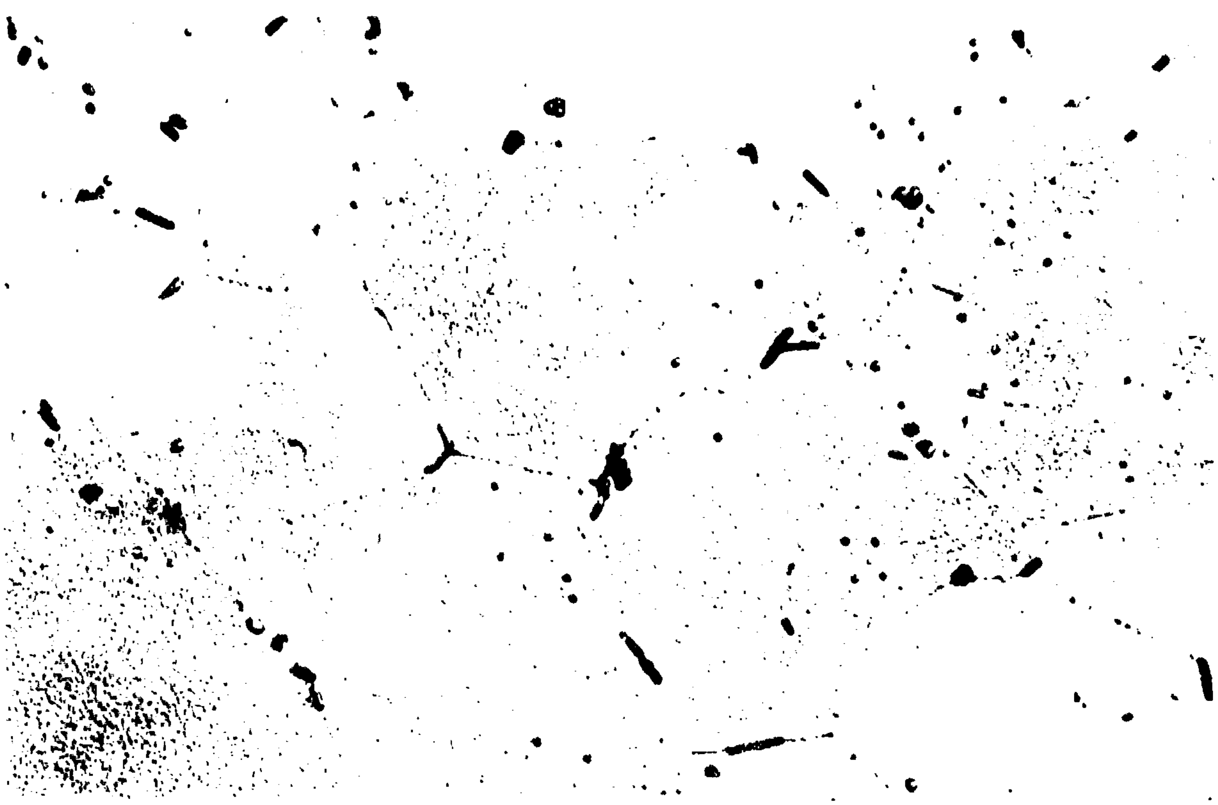


(KELLER'S ETCH) X500 SPECIMEN 128P 85-00239-20B

FIGURE 106. PHOTOMICROGRAPHS OF TYPICAL STRUCTURE OF A201-T7 FRACTURE TOUGHNESS SPECIMEN EXHIBITING 23.2 ksi sqrt inch AT 63.2 ksi Y.S.



(KELLER'S ETCH) X100 SPECIMEN 32-1 85-00237-3A



(KELLER'S ETCH) X500 SPECIMEN 32-1 85 00237-3B

FIGURE 107. PHOTOMICROGRAPHS OF TYPICAL STRUCTURE OF A201-T7 FRACTURE TOUGHNESS SPECIMEN EXHIBITING 32.8 ksi sqrt inch AT 59.2 ksi Y.S.

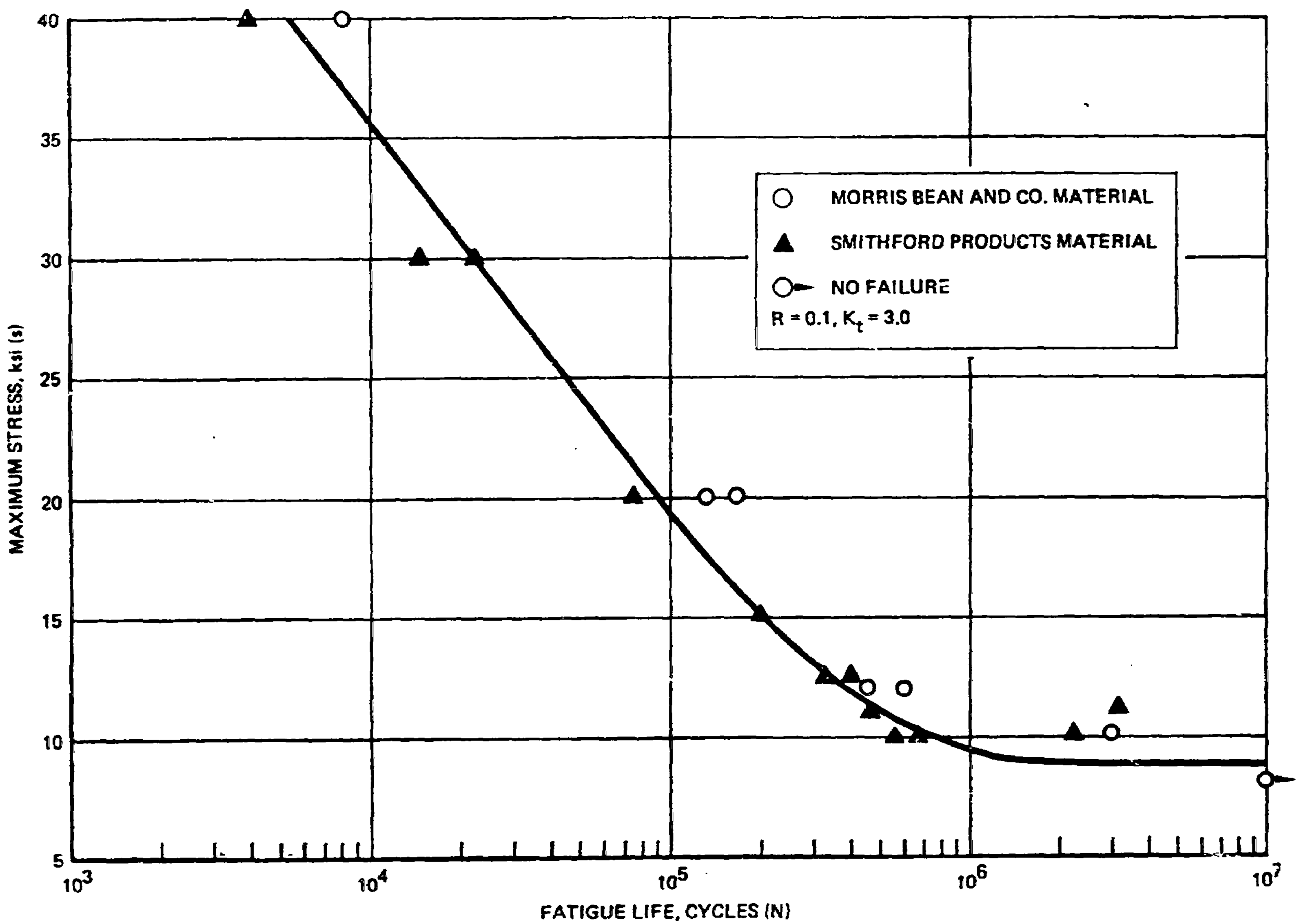


FIGURE 108. S/N PLOT OF NOTCHED FATIGUE PROPERTIES OF A201-T7 MATERIAL

(i) Crack Growth Properties

The results of crack growth testing as shown in Figure 108 were reported by J. Tirpak, 2Lt., USAF, stationed at the AFWAL Material Laboratory. The crack growth characteristics of the material were reported to be similar to those of commonly used wrought products, such as 2124-T851 plate. The AFWAL report is included in the Appendix F.

5. Effect of Weld Improvement

To evaluate the effect of weld improvement on the mechanical properties of the parent cast material, weld coupons were excised from step plates and tested for tensile strength, notched fatigue, and fracture toughness properties. Both A201-T7 and A357-T6 material were included in the evaluation.

a. Weld Procedures

The welding of A357-T6 material was done at Teledyne Cast Products and Magnesium Alloy Products foundries using normal production welding procedures. The A201-T7 material was welded in the following manner at the Northrop Metallics Research Laboratory. Twelve weld coupons, 0.5-inch thick by 2.5 inches wide by 3.0 inches long, were sectioned from the designated area of the step plates. A 60-degree "V" groove was machined in the center of the coupons to a depth of 0.25 inch and parallel to the 3-inch length. A 3/32-inch radius was machined at the bottom of the groove and a 3/16-inch radius was added to the corners. After machining the groove, the coupons were chemically cleaned in 47-percent HNO_3, 3-percent HF, and 50-percent H_2O solution, then rinsed with tap water and deionized water and air dried. Welding was conducted by the GTA welding process with direct-current, straight-polarity, and 100-percent helium shielding. The filler metal was A201 material 0.094 inch in diameter. Prior to welding, the rod was cleaned with "Scotch Brite" and wiped with acetone to remove any foreign particles. The welding parameters for each pass were as follows:

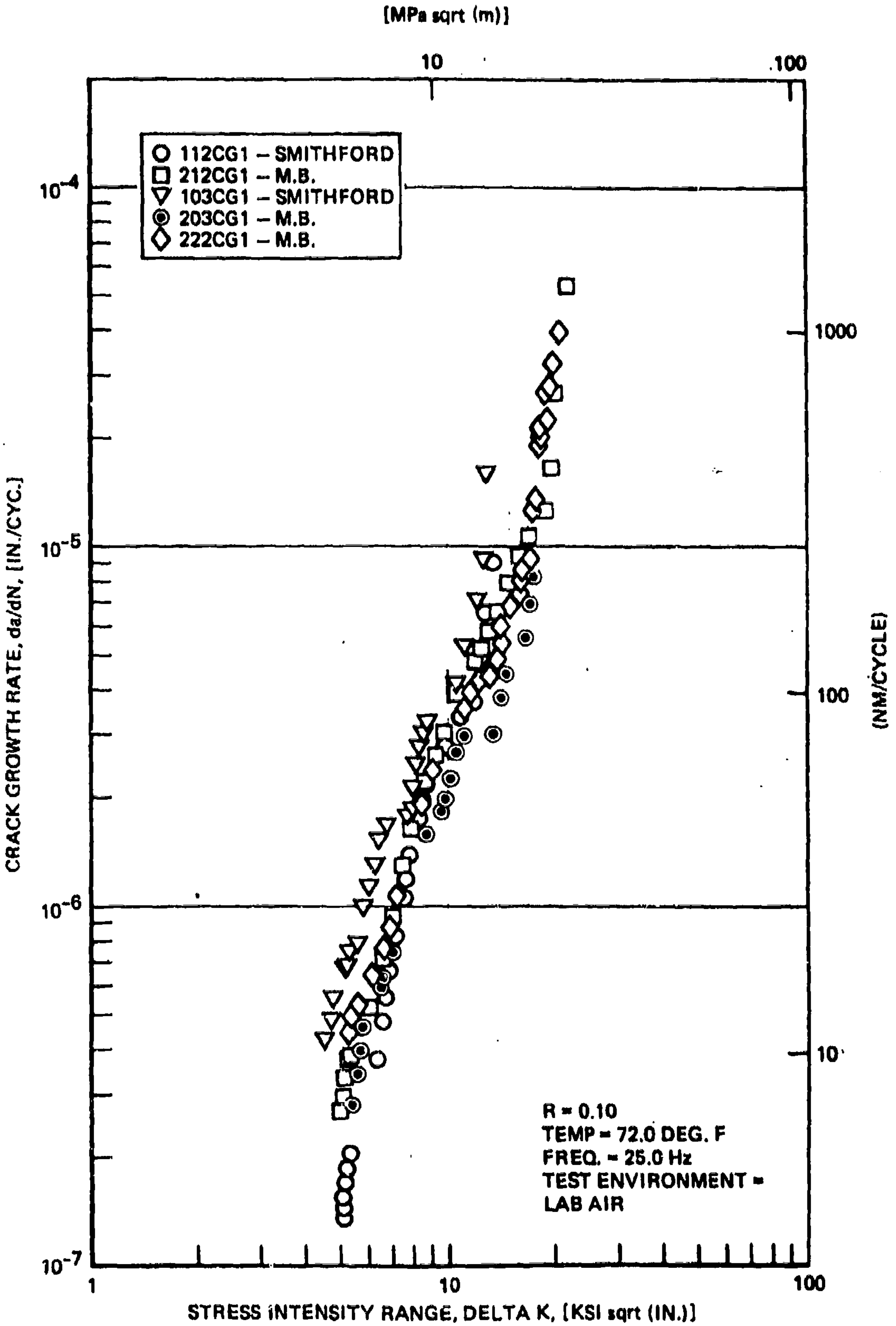


FIGURE 109. COMBINED PLOT OF FATIGUE CRACK GROWTH DATA FOR A201 SPECIMENS

Group No.	Plate No.	Pass No.	Current (amps)	Voltage (v)
	222	1	150	20
	219	2	140-160	20-22
1	123	3	120-130	18
	221	4	130-140	20
	122	1	160	22
	120	2	150-160	20-22
2	119	3	130-140	20
	224	4	130-140	20
	132	1	160	20
	133	2	140-150	20-22
3	124	3	120-130	20
	121	4	130-140	20

The composition of the weld wire was as follows:

Copper	4.87%
Silver	0.57%
Manganese	0.37%
Magnesium	0.25%
Titanium	0.19%
Iron	0.03%
Silicon	0.03%
Aluminum	Remainder

b. Test Procedure

All welded step plates were inspected using radiography and fluorescent penetrant techniques prior to machining the test specimens. The specimens were machined as shown in Figure 109, such that the weld was located in the middle of the tensile specimen and in the notched area of the fatigue specimen. The compact tension fracture toughness specimens were machined such that the weld was located in and ahead of the machined notch. In addition, all machined test specimens were x-rayed prior to testing to ensure the correct location of the weld.

c. Test Results

(1) A357 Alloy

(a) Tensile Properties

Magnesium Alloy Products Step Plate Material

Test Specimen	TUS (ksi)	TYS (ksi)	e (%)
16-T1	54.4	45.0	5.0
16-T2	55.8	47.5	7.0
20-T1	55.8	45.8	8.0
20-T2	56.4	47.1	8.0
32-T1	55.6	45.6	9.0
32-T2	55.2	45.2	9.0
Average (weld)	55.5	46.0	7.7
Average (parent metal)	55.0	47.2	6.4

Teledyne Cast Products Step Plate Material

Test Specimen	TUS (ksi)	TYS (ksi)	e (%)
81-T1	52.5	43.5	8.0
81-T2	51.5	43.4	6.0
81-T3	52.3	43.8	7.0
Average (weld)	52.1	43.6	7.0
Average (parent metal)	53.4	45.3	5.5

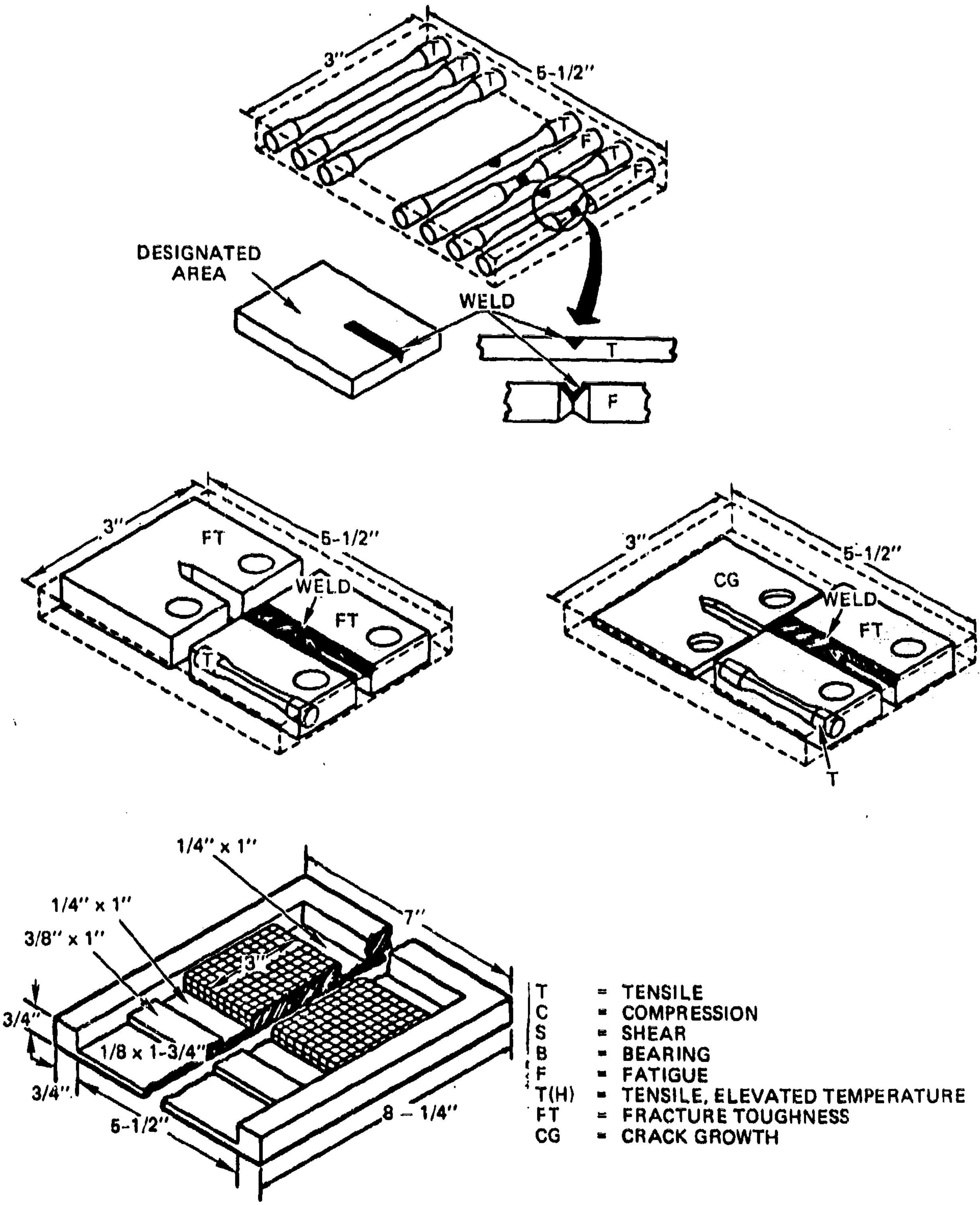


FIGURE 110. LOCATION OF WELDED SPECIMENS WITHIN THE DESIGNATED AREA OF THE STEP PLATE

(b) Fracture Toughness Properties: Magnesium Alloy Products Step Plate Material (all specimens were of insufficient thickness to obtain a valid K_{IC} value).

WELD AREA			NON-WELDED AREA		
Test Specimen	Yield Strength (ksi)	K_Q (ksi $\sqrt{}$ in)	Test Specimen	Yield Strength (ksi)	K_Q (ksi $\sqrt{}$ in)
37-FT1	43.8	27.4	15-FT1	45.5	20.8
38-FT1	45.8	22.3	36-FT1	43.6	18.5
39-FT1	44.6	22.8	39-FT1	44.6	25.2
Average	44.7	24.2	Average	44.6	21.5

(c) Notch Fatigue Properties

The effects of weld improvement on notch fatigue behavior of Teledyne Cast Products and Magnesium Alloy Products test material are shown in Figure 110.

(d) Conclusions

Weld improvement processing of cast A357 was successful in restoring tensile and fracture toughness properties; however, a degradation of 2 to 3 ksi occurred in notched fatigue properties after 500,000 cycles.

(2) A201 Alloy

(a) Tensile Properties: Smithford Product Step Plate Material

Test Specimen	TUS (ksi)	TYS (ksi)	e (%)
120-T2	62.6	55.8	5.0
122-T2	68.0	59.6	8.0
123-T2	67.9	61.2	4.0
Average (weld)	66.2	58.9	5.3
Average (parent metal)	64.0	58.0	5.6

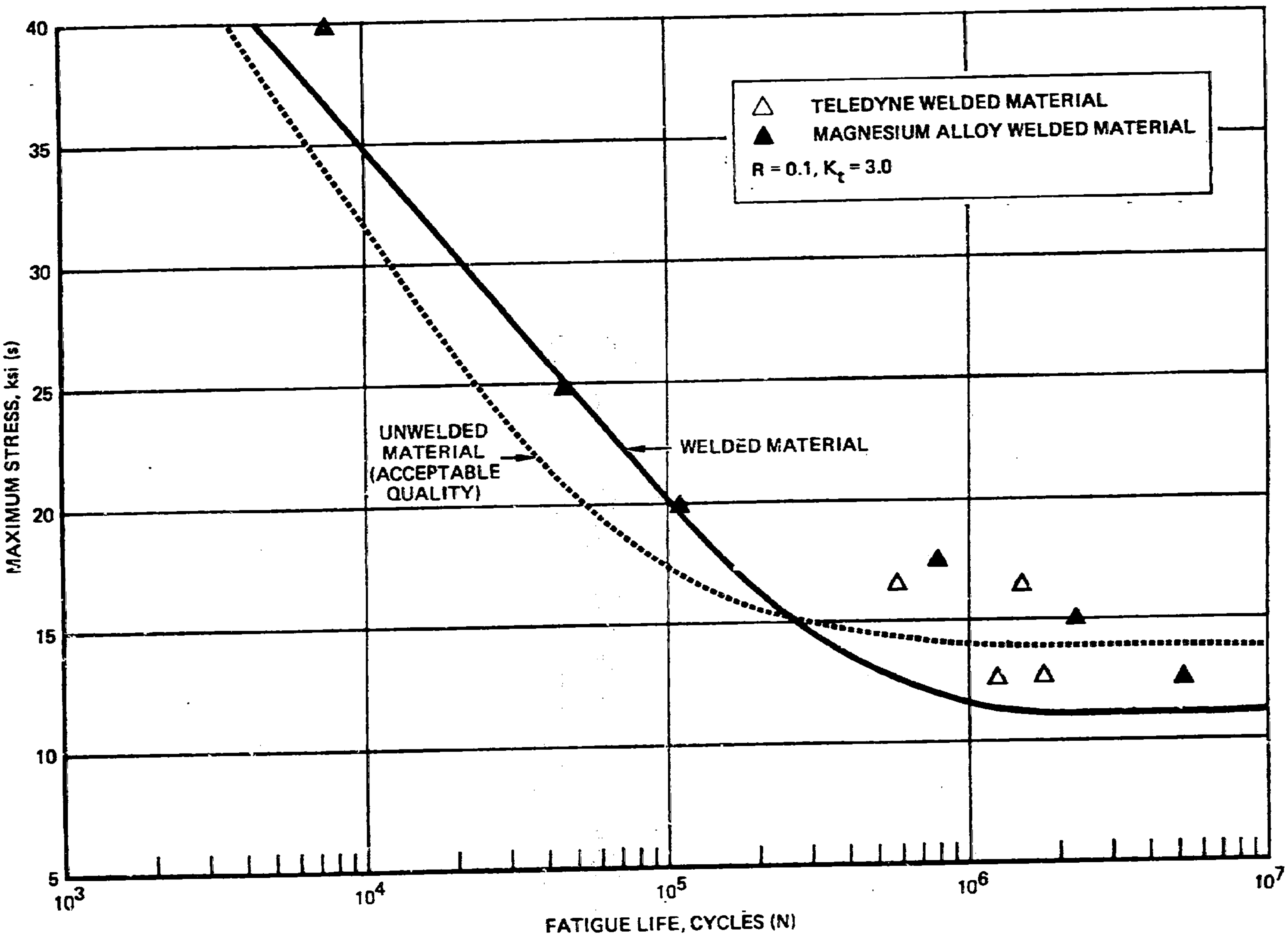


FIGURE 111. S/N FATIGUE PROPERTIES OF DEFECTIVE A357-T6 MATERIAL AFTER WELD IMPROVEMENT

Morris Bean and Company Step Plate Material

Test Specimen	TUS (ksi)	TYS (ksi)	e (%)
219-T1	69.0	61.3	7.0
224-T2	68.8	62.3	6.0
224-T3	67.0	59.7	8.0
Average (weld)	68.3	61.1	7.0
Average (parent metal)	65.8	60.2	5.6

(b) Fracture Toughness Properties: Smithford Products Company Step Plate Material

Test Specimen	K_Q, ksi in
215-4	37.3
215-5	37.4
Average (weld)	37.4
Average (parent metal)	27.2

Morris Bean and Company Step Plate Material

Test Specimen	K_Q, ksi in
33-2	34.8
Average (parent metal)	29.0

(c) Notch Fatigue Properties

The effects of weld improvement on the notch fatigue behavior of A201-T7 material is shown in Figure 111.

(d) Conclusions

The results of weld improvement processing of A201-T7 cast material indicated that tensile properties of the material were not changed, fracture toughness was improved, and the notched fatigue properties were

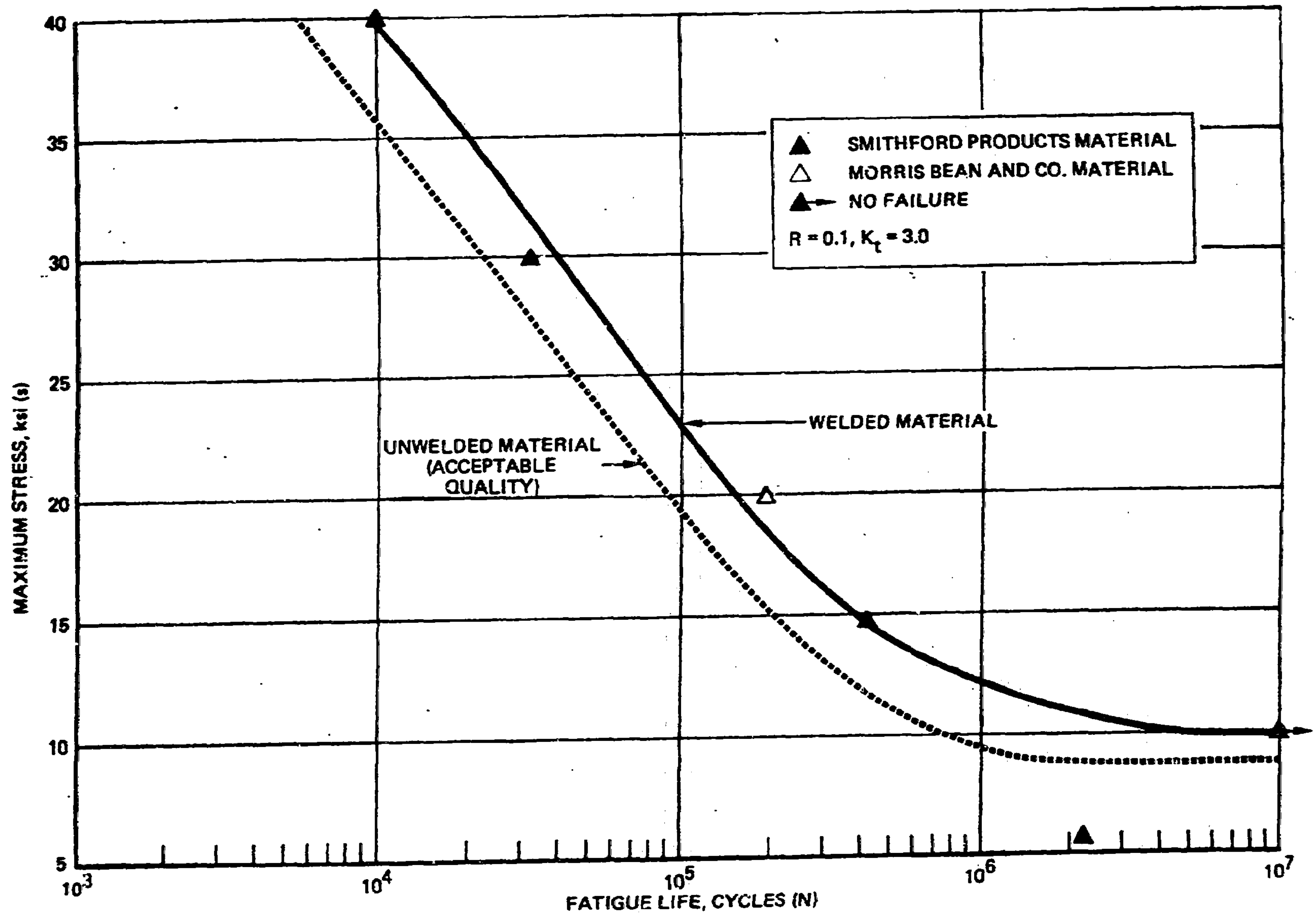


FIGURE 112. S/N FATIGUE PROPERTIES OF DEFECTIVE A201-T7 MATERIAL AFTER WELD IMPROVEMENT

improved in tests up to 1,000,000 cycles; beyond 1,000,000 cycles, the effect was not clear due to the lack of sufficient data.

6. Effect of Radiographic Unsoundness

a. Procedure

Step plates were produced to less than a Grade C (per MIL-C-6021 and Table 49) radiographic quality, and evaluated to determine the effect of unsoundness on tensile, fracture toughness, and notched fatigue properties. Test specimens were excised from the designated casting area and reinspected after machining to their final configuration to confirm the unsoundness quality of the test material. With the exception of the radiographic quality, the material was produced using the same procedures as the other step plates evaluated in the program.

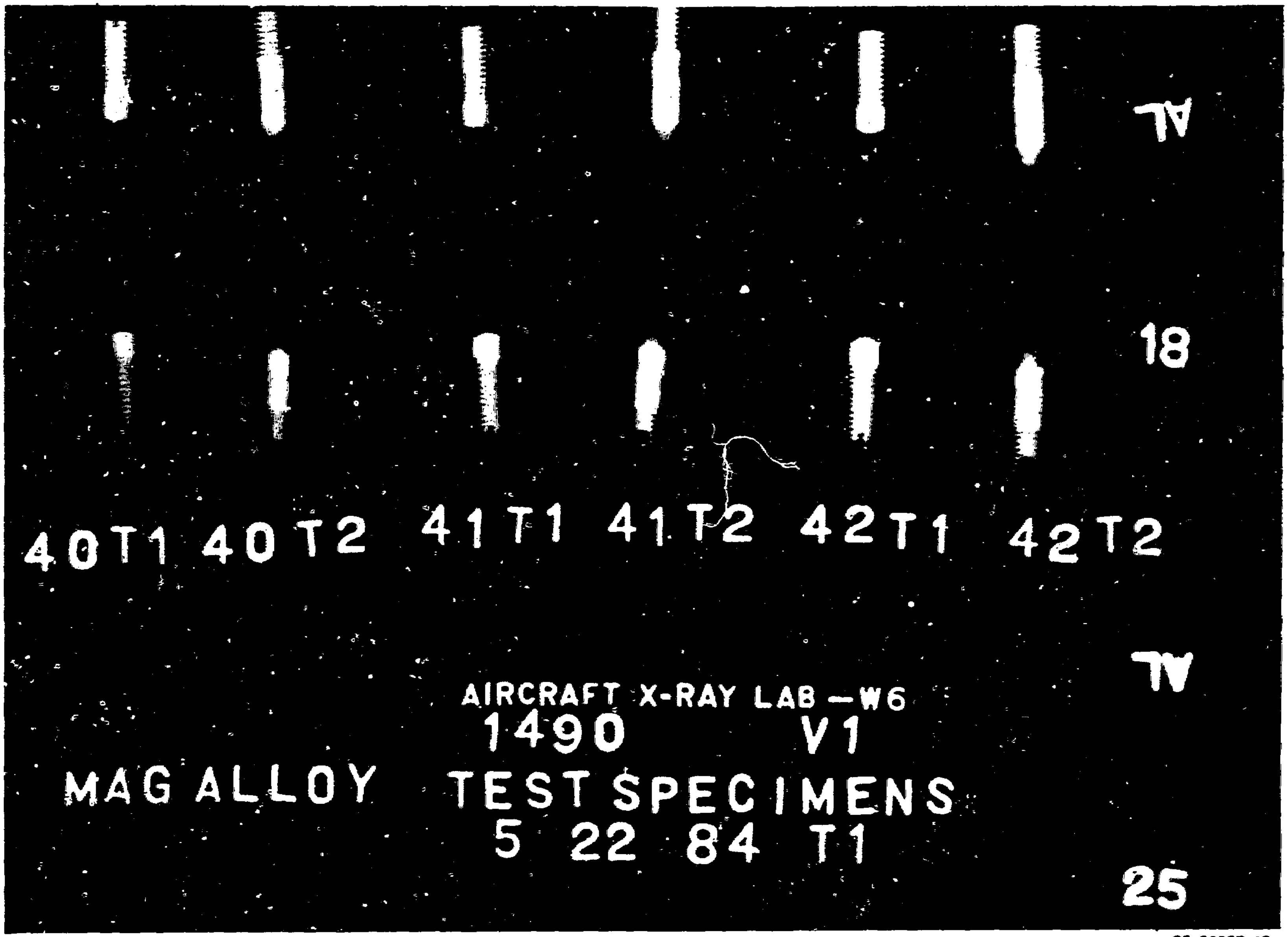
b. Test Results

(1) A357 Alloy

(a) Tensile Properties
Magnesium Alloy Products:

Test Specimen	TUS (ksi)	TYS (ksi)	e (%)	Discontinuity, ASTM Plate No. (Grade D)
40-T1	46.4	42.0	2.0	Sponge Shrinkage, No. 4
41-T1	40.7	39.7	2.0	Sponge Shrinkage, No. 4
42-T1	44.4	42.2	1.0	Sponge Shrinkage, No. 4
Average Gr-D	43.8	41.3	1.8	
Average Gr-B	55.0	47.2	6.4	

The Grade D quality of the tensile specimens are shown in Figure 112. A maximum severity of permissible sponge shrinkage is depicted in ASTM Plate 4 for Grade D quality casting.



85-00237-13

FIGURE 113. PHOTOGRAPHIC REPRODUCTION OF RADIOGRAPH DEPICTING SPONGE SHRINKAGE IN A357-T6 TENSILE SPECIMENS

TABLE 49. MIL-C-6021 RADIOGRAPHIC SEVERITY LEVEL REQUIREMENTS FOR ALUMINUM CASTINGS PER ASTM E155

Discontinuity	Radiograph	Grade A Inch 1/4	Grade A Inch 3/4	Grade B (Thickness) Inch 1/4	Grade B (Thickness) Inch 3/4	Grade C Inch 1/4	Grade C Inch 3/4	Grade D Inch 1/4	Grade D Inch 3/4
		(ASTM Plate Number)							
Gas holes	1.1	None		1	1	2	2	5	5
Gas porosity (round)	1.21	None		1	1	3	3	7	7
Gas porosity (elongated)	1.22	None		1	2	3	4	5	5
Shrinkage cavity	2.1	None		1	NA 1/	2	NA 1/	3	NA 1/
Shrinkage porosity or sponge	2.2	None		1	1	2	2	4	3
Foreign material (less dense material)	3.11	None		1	1	2	2	4	4
Foreign material (more dense material)	3.12	None		1	1	2	1	4	3
Segregation	3.2	None		None		None		None	
Cracks	NA 1/	None		None		None		None	
Cold Shuts	NA 1/	None		None		None		None	
Surface irregularity	NA 1/	Not to exceed drawing tolerance							
Core shift	NA 1/	Not to exceed drawing tolerance							

1/ Not available

NOTE: The 1/4-inch thickness requirements are to be used for material up to and including 1/2 inch.

The 3/4-inch thickness requirements are to be used for material from 1/2 inch to and including 2 inches.

Teledyne Cast Products:

Test Specimen	TUS (ksi)	TYS (ksi)	e (%)	Discontinuity, ASTM Plate No. (Grade C-D)
83-T1	48.4	42.4	3.0	Rd Gas Porosity, No. 4
83-T2	47.7	41.6	3.0	Rd Gas Porosity, No. 7
82-T1	46.7	41.0	3.0	Rd Gas Porosity, No. 7
82-T2	48.8	42.7	4.0	Rd Gas Porosity, No. 4
81-T1	48.7	42.3	4.0	Rd Gas Porosity, No. 4
81-T2	45.4	41.8	2.0	Rd Gas Porosity, No. 4
Average Gr C-D	47.6	42.0	3.3	
Average Gr B	53.4	45.3	5.5	

Figure 113 depicts the Grade C to D radiographic quality of the specimens. The maximum round gas porosity allowed is ASTM Plate No. 3 for Grade C and 7 for Grade D.

(b) Notch Fatigue Properties

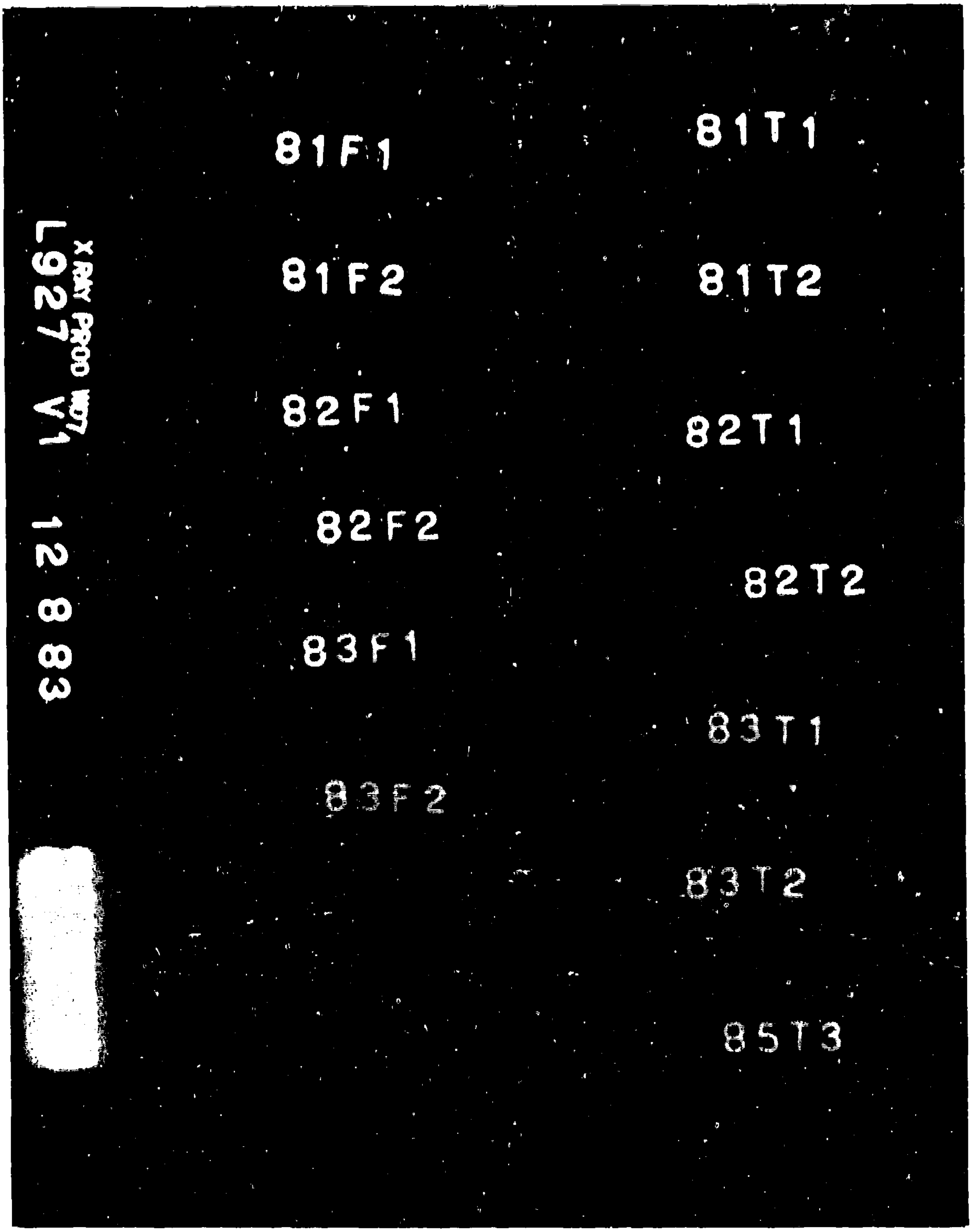
The effect of Grade D gas porosity and Grade C sponge snrinkage on notch fatigue behavior of A357 alloy is shown in Figure 114. The radiographic quality of the specimens is depicted in Figures 113.

(c) Fracture Toughness Properties

Magnesium Alloy Product:

Test Specimen	K_Q, ksi in	Discontinuity, ASTM Plate No.
40-FT1	25.1	Sponge Shrinkage, No. 6
41-FT1	22.5	Sponge Shrinkage, No. 7
44-FT1	23.0	Sponge Shrinkage, No. 6
Average (Grade worse than D)	23.3	
Average (Grade B material)	22.0	

The radiographic quality is shown in Figure 115. The maximum sponge shrinkage allowed for Grade D material is ASTM Plate No. 4.



85-00237-10

FIGURE 114. PHOTOGRAPHIC REPRODUCTION OF RADIOGRAPH SHOWING GAS POROSITY IN A357-T6 TENSILE SPECIMENS AND GAS POROSITY AND SPONGE SHRINKAGE IN NOTCHED FATIGUE SPECIMENS

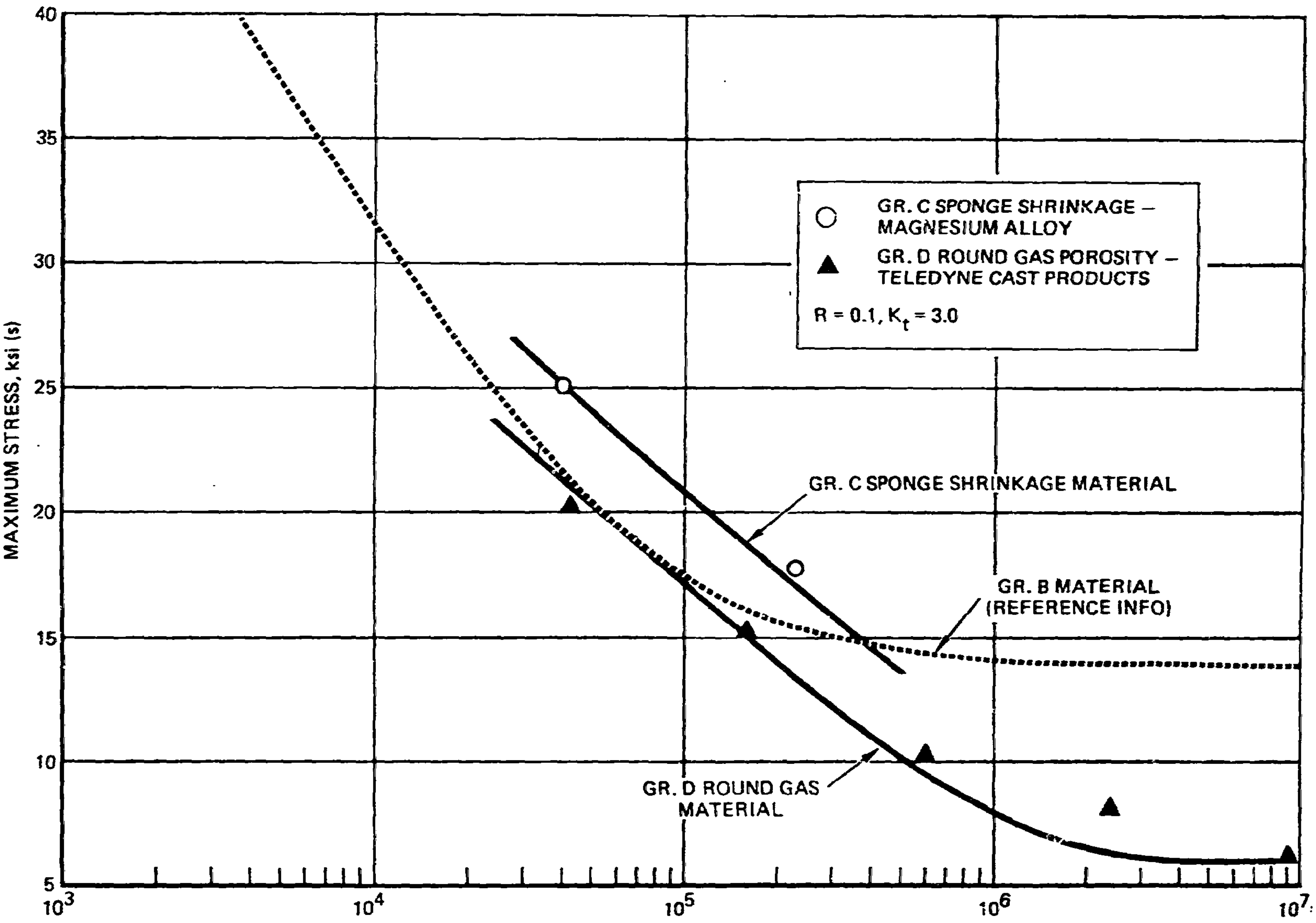
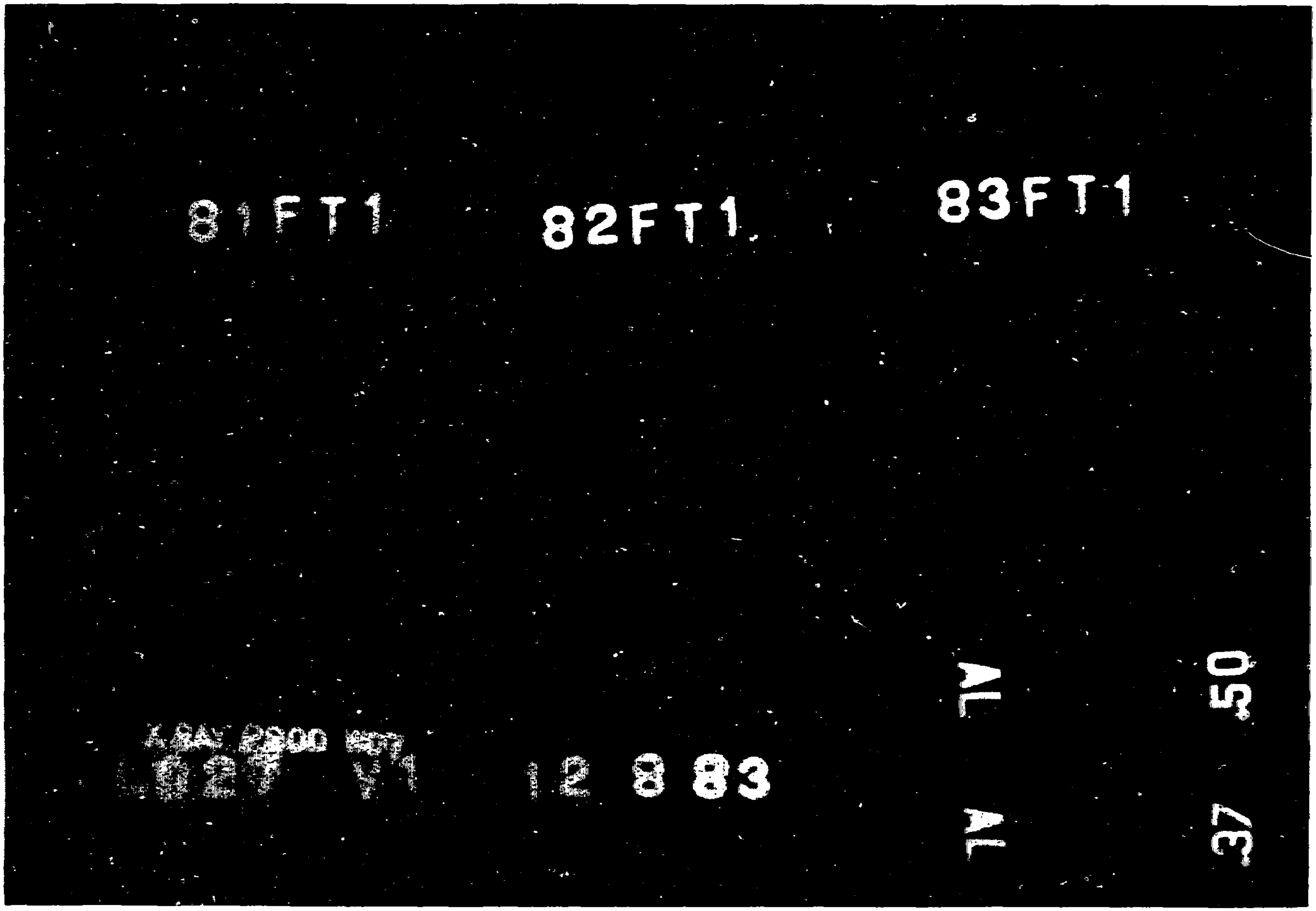


FIGURE 115. EFFECT OF RADIOGRAPHIC UNSOUNDNESS ON NOTCHED FATIGUE PROPERTIES OF A357-T6 MATERIAL



85-00237-8

FIGURE 116. PHOTOGRAPHIC REPRODUCTION OF RADIOGRAPH SHOWING SPONGE SHRINKAGE EVALUATED IN A357-T6 FRACTURE TOUGHNESS SPECIMENS

(d) Conclusions

Tensile property values of ultimate strength and elongation were reduced due to the presence of Grade C-D sponge shrinkage and Grade D gas porosity. Notched fatigue strength was significantly reduced by the presence of Grade D round gas porosity. However Grade C sponge shrinkage appeared to have much less effect although the data was very limited. Fracture toughness, K_Q values, were not affected by the presence of Grade C-D sponge shrinkage.

(2) A201 Alloy

(a) Tensile Properties

Smithford Cast Products

Test Specimen	TUS (ksi)	TYS (ksi)	e (%)	Discontinuity, ASTM Plate No. (Grade D)
117-T1	56.7	54.9	1.0	Rd Gas Porosity, No. 7
117-T2	57.1	55.4	1.0	Rd Gas Porosity, No. 7
118-T1	59.3	56.9	1.0	Rd Gas Porosity, No. 6
118-T2	59.8	57.2	1.0	Rd Gas Porosity, No. 6
Average Grade C to D	58.2	56.1	1.0	
Average Grade B material	64.0	58.0	5.6	

Figure 116 shows the radiographic quality of the test specimens.

Morris Bean and Company

Six tensile specimens were machined from the three defective step plates submitted by Morris Bean and Company. However, after machining and radiographic examination, the test material was Grade B instead of Grade C. Apparently, the Grade C defects shown originally were superficial and were removed during machining. Therefore, the tensile test was not performed.

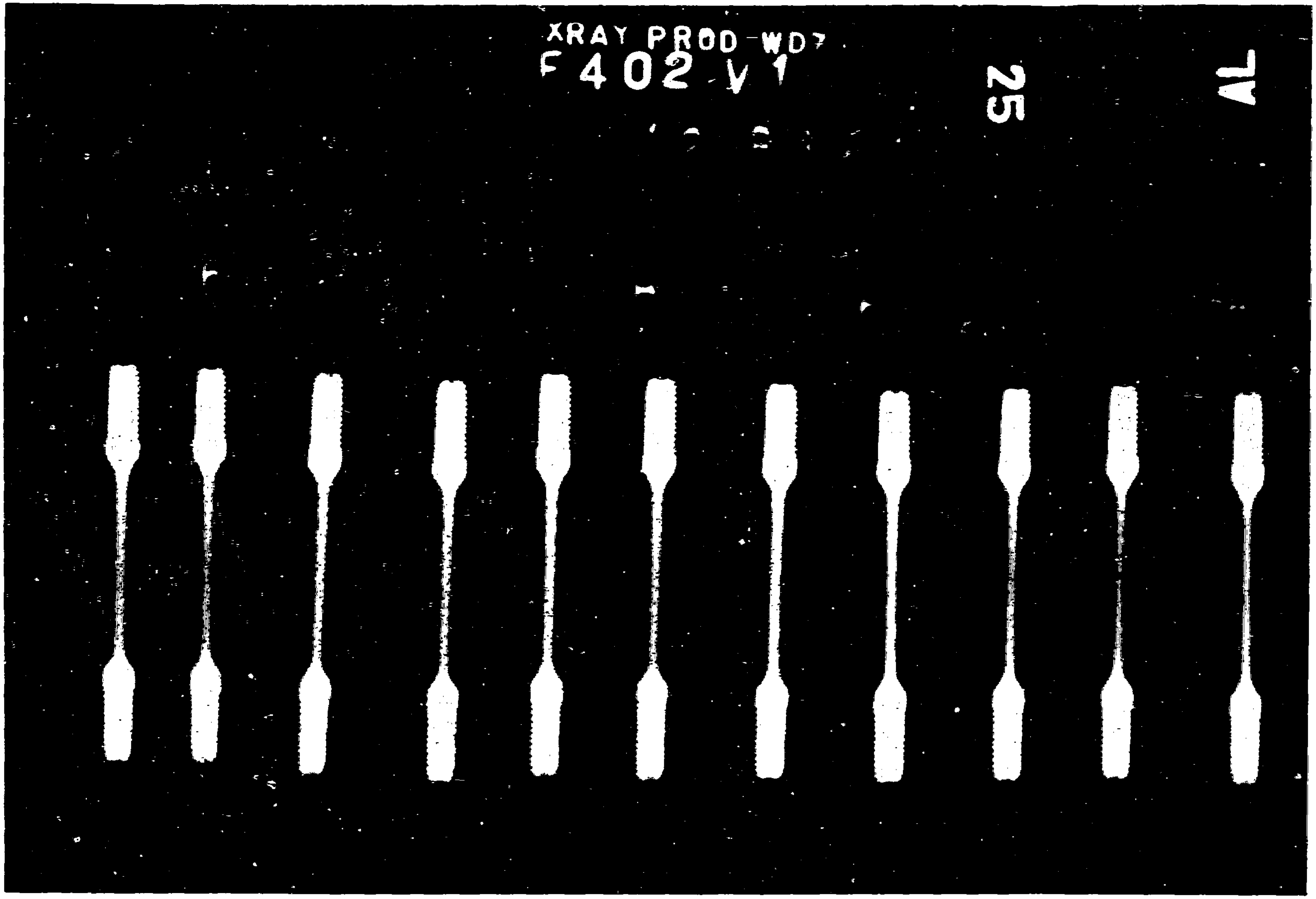


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FIGURE 117. PHOTOGRAPHIC REPRODUCTION OF RADIOGRAPH SHOWING ROUND GAS POROSITY EVALUATED IN A201-T7 TENSILE SPECIMENS

(b) Notch Fatigue Properties

The effect of Grade C to D radiographic quality (as shown in Figure 117) on the notch fatigue behavior of A201 alloy is shown in Figure 118. Grade D round gas porosity, ASTM Plate No. 6 and 7 lowered the fatigue resistance at both high and low stress levels.

(c) Fracture Toughness Properties

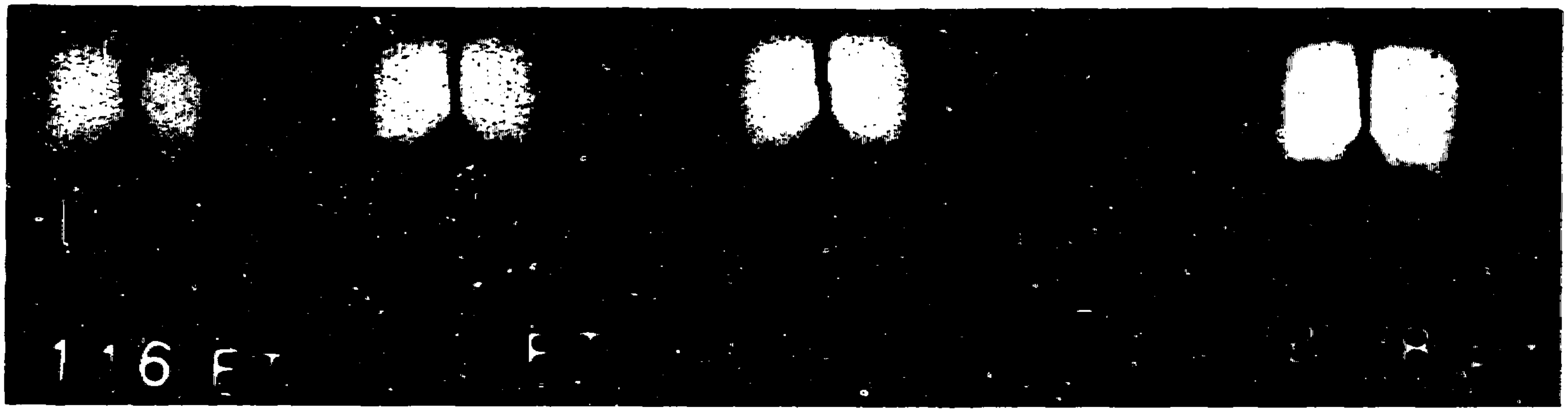
Smithford Product

Test Specimen	K_Q, ksi in	Discontinuity, ASTM Plate No. (Grade D)
115-FT-1	22.8	Rd Porosity, No. 5
117-FT-1	23.4 (k_{Ic})	Rd Porosity, No. 6
118-FT-1	25.3 (k_{Ic})	Rd Proosity, No. 6
Ave Gr-D	24.4	
Ave Gr-B	27.2	

(d) Conclusions

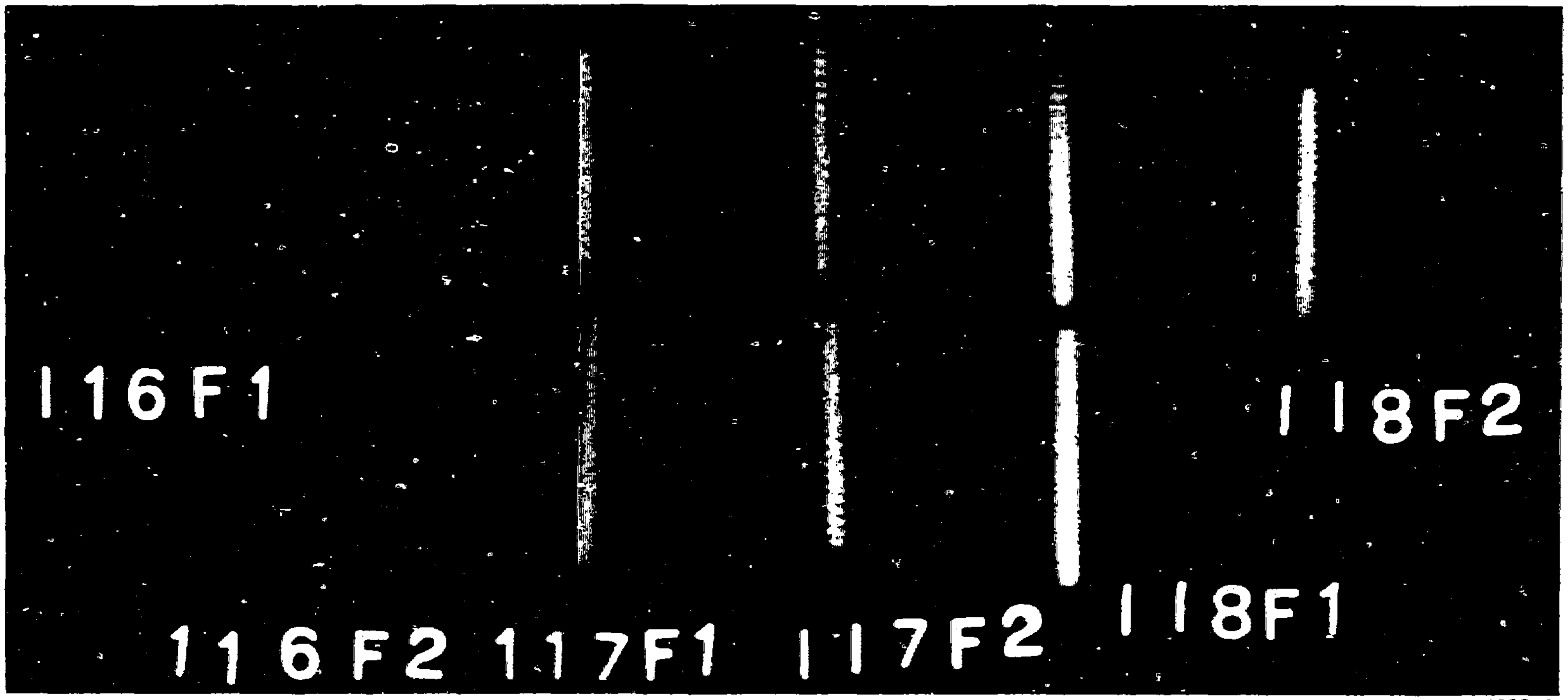
Tensile ultimate strength and elongation were significantly reduced because of Grade D round gas porosity in the material.

Grade D round gas porosity reduced the notched fatigue endurance limits of the material 20 to 30 percent and fracture toughness approximately 10 percent.



FRACTURE TOUGHNESS SPECIMENS

85-00238-6



NOTCHED FATIGUE SPECIMENS

85-00238-4

FIGURE 118. PHOTOGRAPHIC REPRODUCTION OF RADIOGRAPH SHOWING ROUND GAS POROSITY EVALUATED IN A201-T7 NOTCHED FATIGUE AND FRACTURE TOUGHNESS SPECIMENS

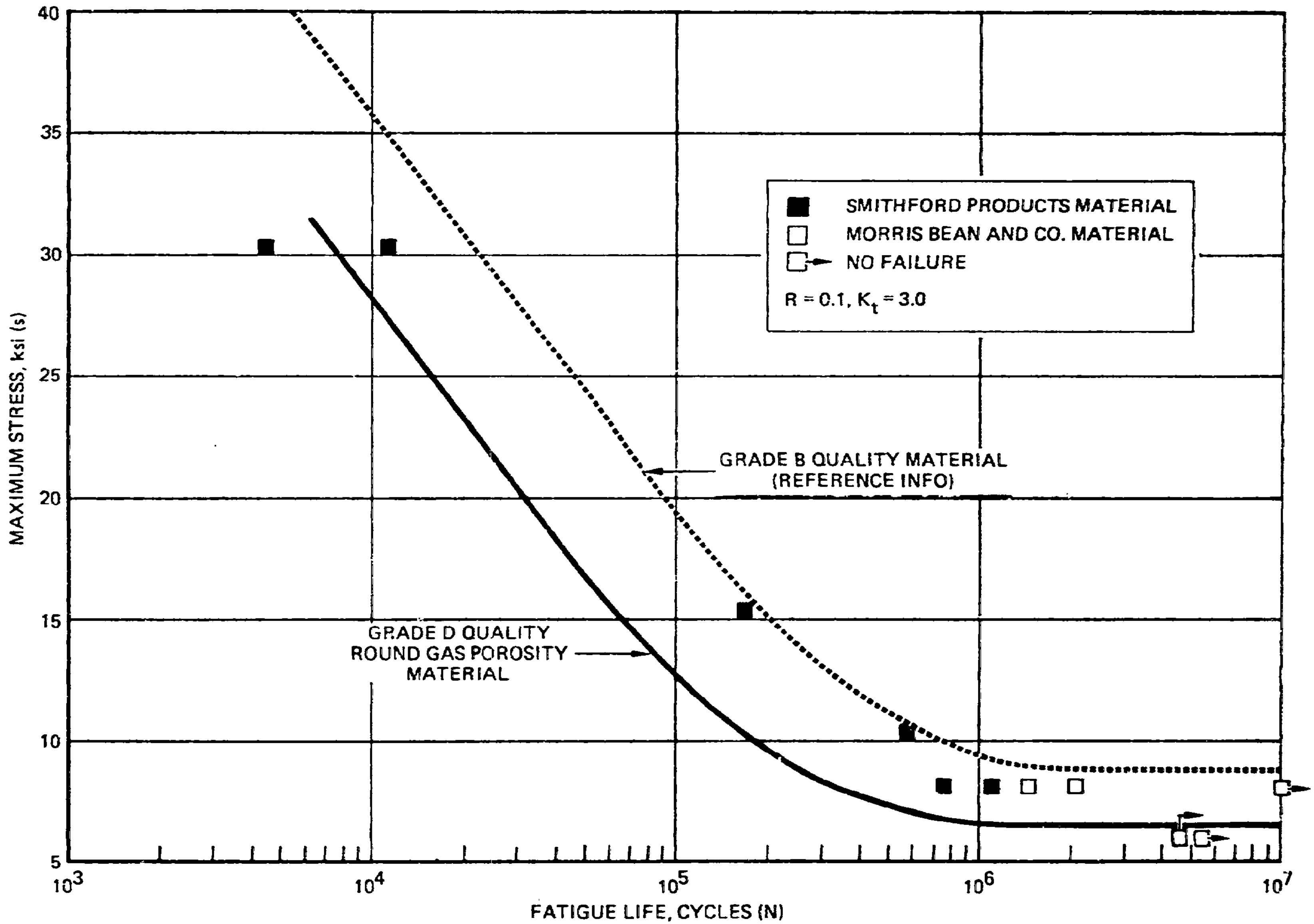


FIGURE 119. EFFECT OF RADIOGRAPHIC UNSOUNDNESS ON NOTCHED FATIGUE PROPERTIES OF A201-T7 MATERIAL

SECTION X

VERIFICATION OF QUALITY ASSURANCE ACCEPTANCE (QAA) PROCEDURE

1. INTRODUCTION

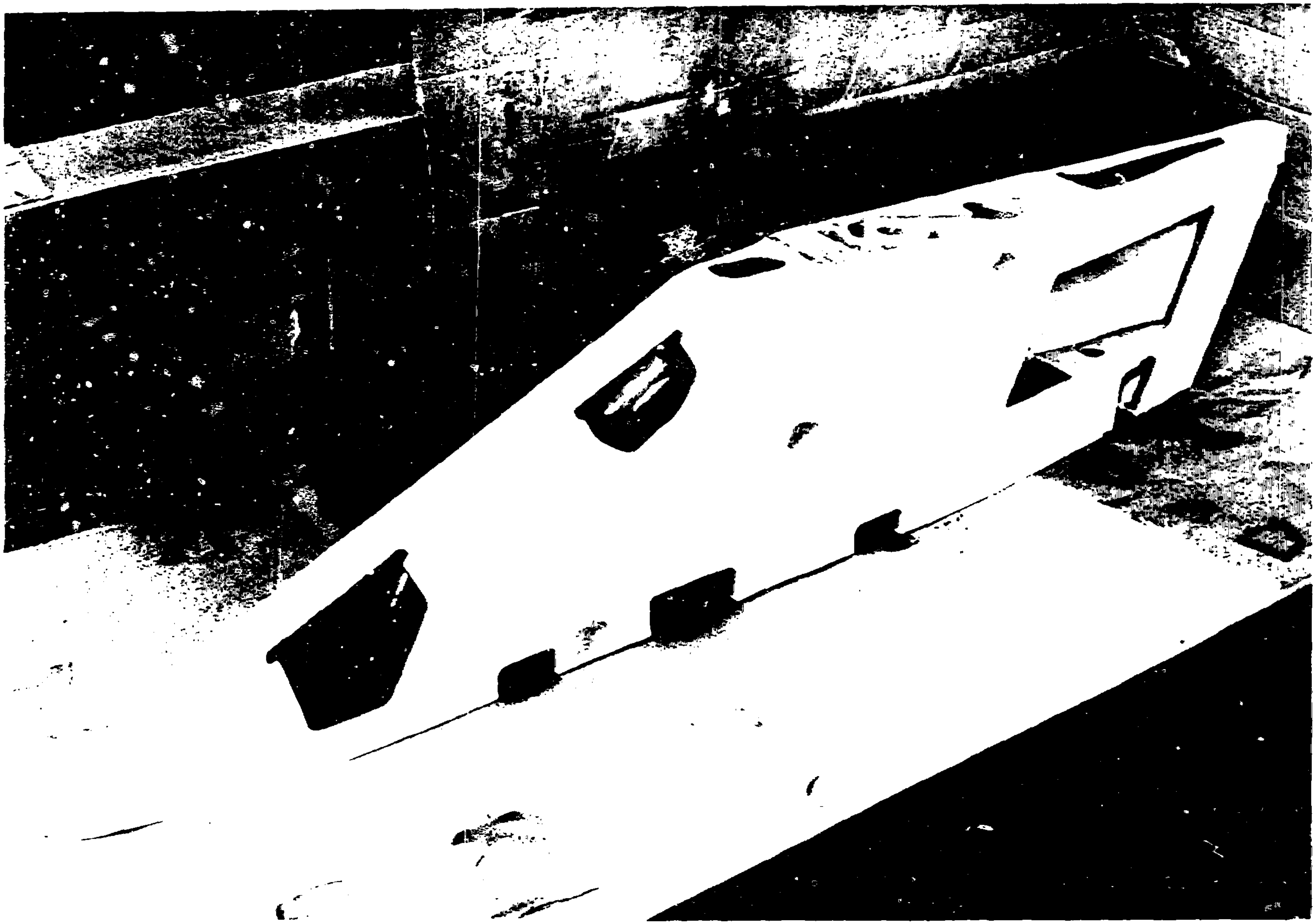
Specifications, such as MIL-A-21180, provide only radiographic and penetrant inspection of each casting to ensure a consistency of tensile property capability. This has not been sufficient to ensure consistent results.

Quality Assurance Acceptance (QAA) procedures and criteria have been developed that will correlate with and reliably predict the tensile property capability of castings. Such inspection procedures and acceptance criteria were established for A357-T6 and A201-T7 castings. To demonstrate the applicability of these criteria to typical configurations of the aerospace industry various Airframe manufacturers were solicited to provide a test configuration for evaluation. Three configurations of A357-T6 material and three configurations of A201-T7 material were obtained as shown in Figures 1 through 6. The process history of each casting was unknown.

2. TEST PROCEDURE

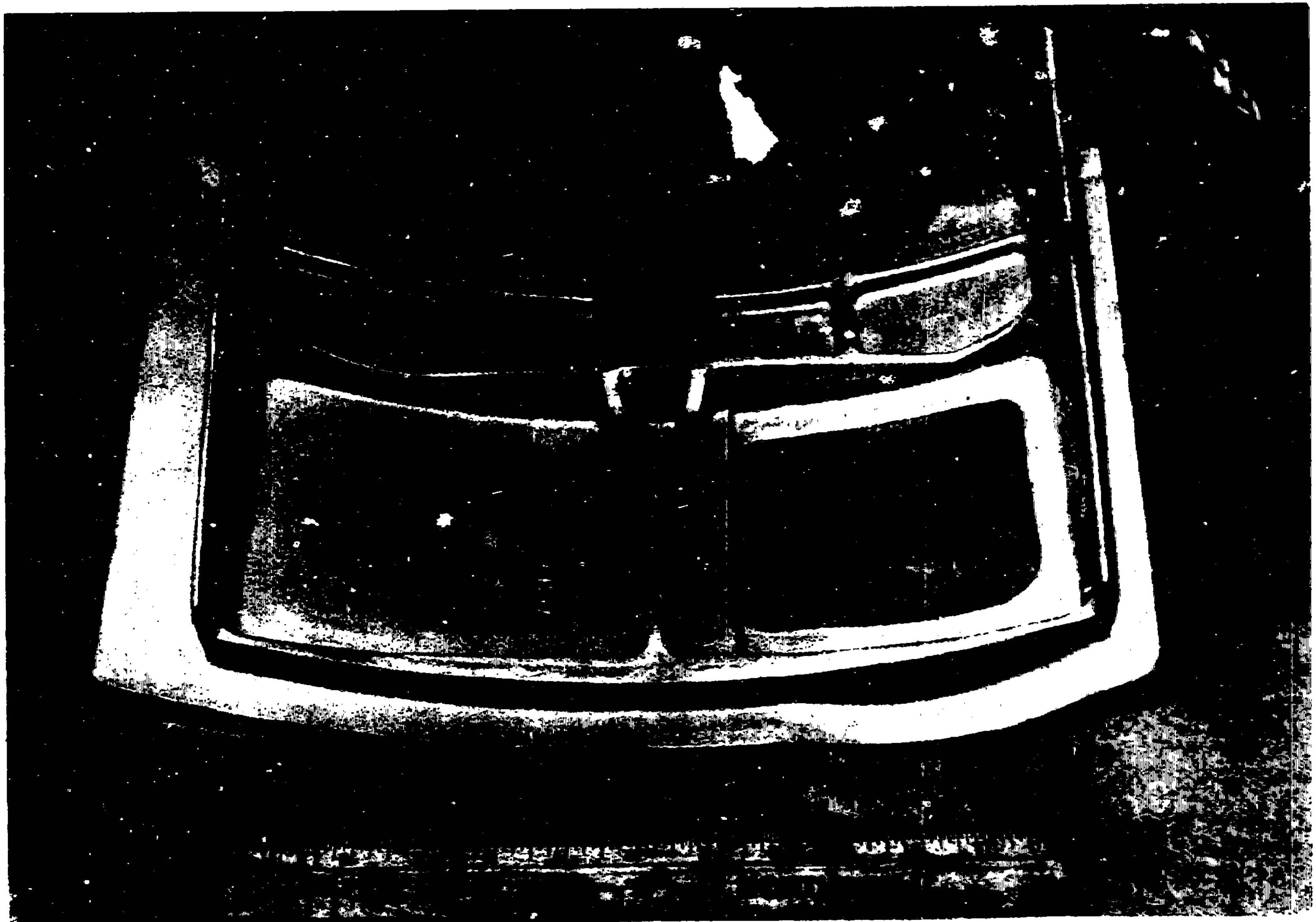
Each casting was evaluated in accordance with the QAA Requirements previously established and included in specifications contained in Appendix H. In lieu of a melt analysis, the chemical composition was determined from a sample cut from the casting. Since none of the castings had integrally attached coupons, it was necessary to excise a test coupon from an area of the casting to simulate an attached coupon. The QAA test requirements were as follows:

Process Variable	Test Method	Acceptance Criteria
Composition	Spectrographic Analysis Report of Melt Sample	Specification Composition Limits



78 06298 6

FIGURE 120. CASTING NO. 1, A357 ALLOY



83 01416 11

FIGURE 121. CASTING NO. 2, A357 ALLOY

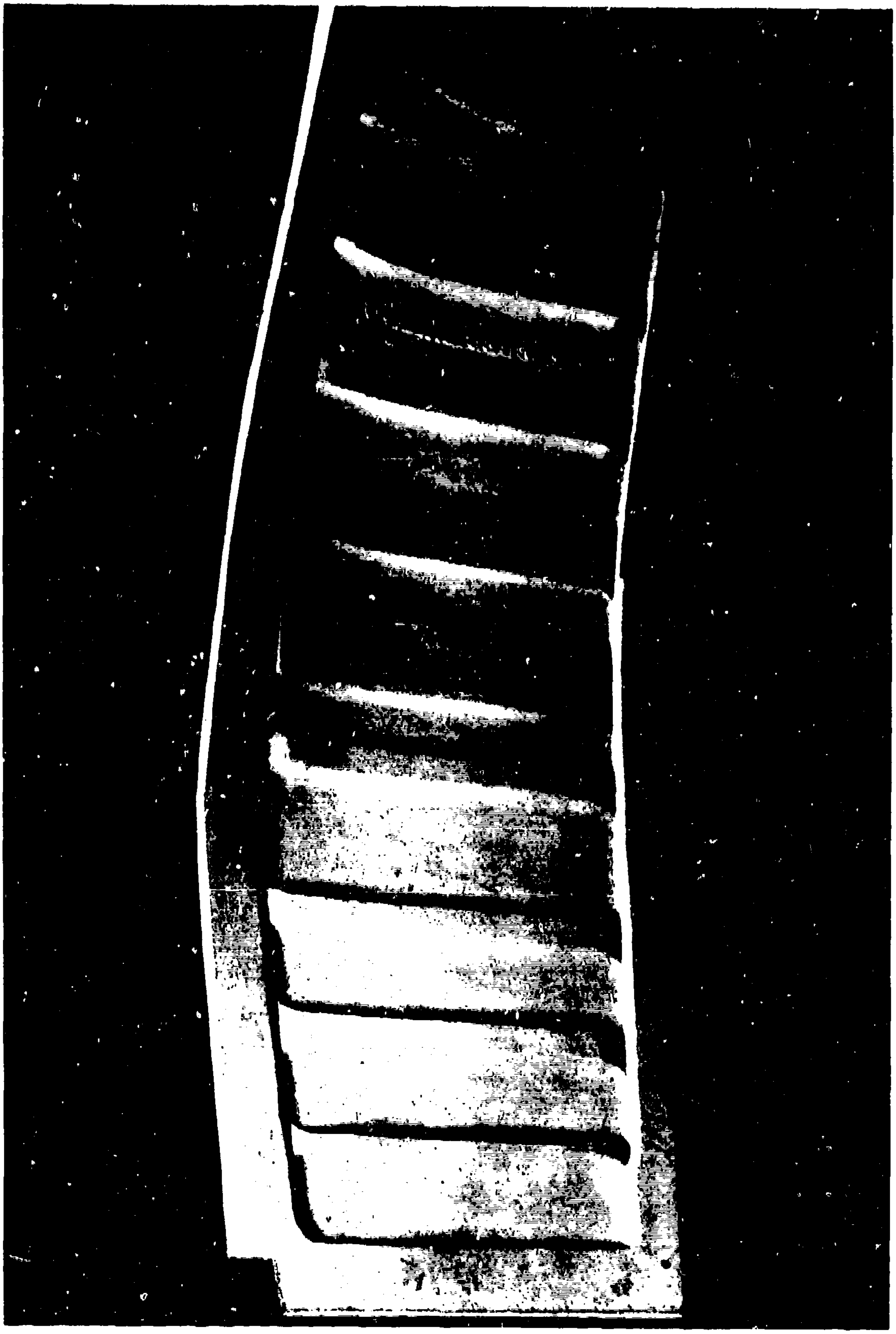


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FIGURE 122. CASTING NO. 3, A357 ALLOY

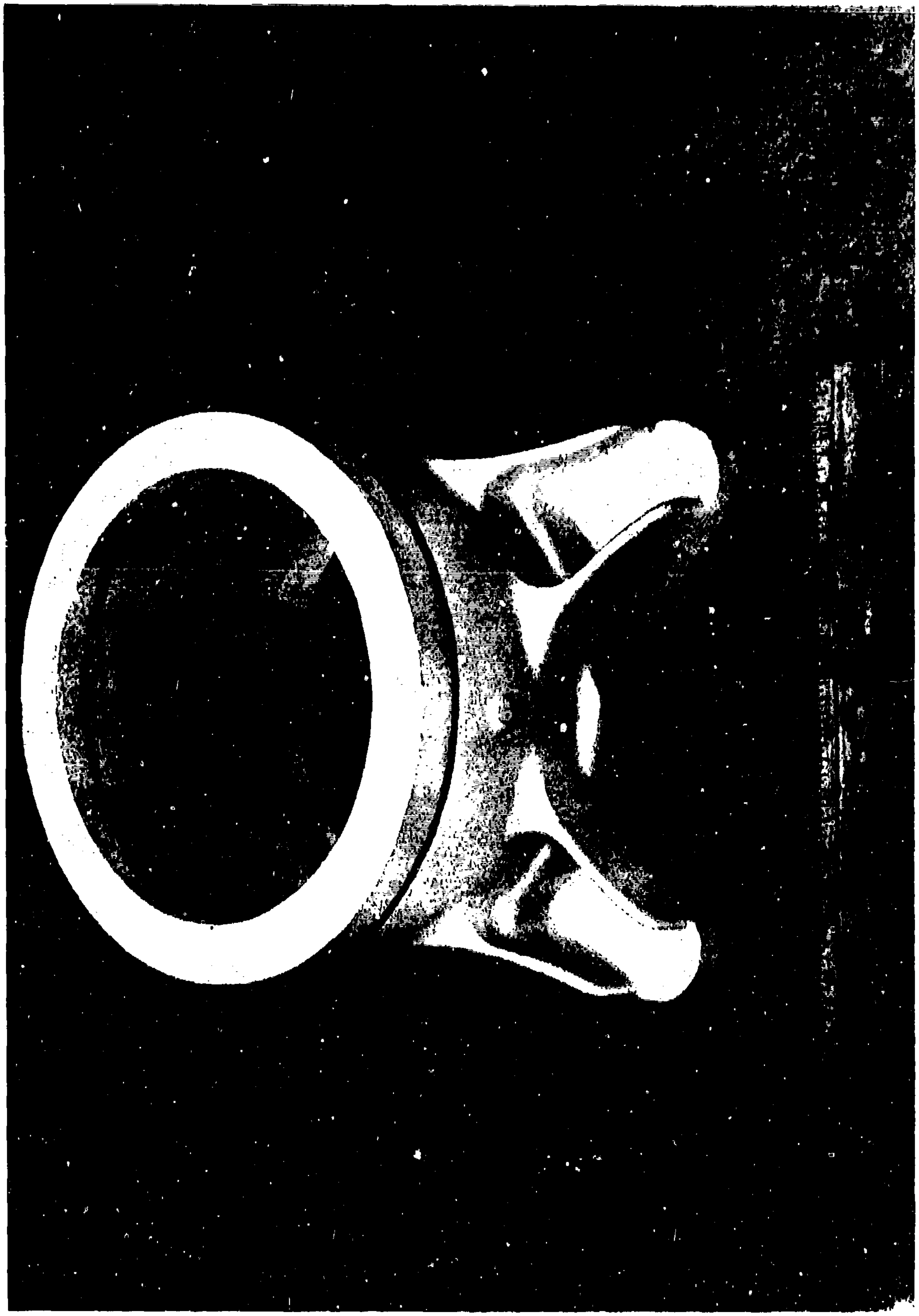
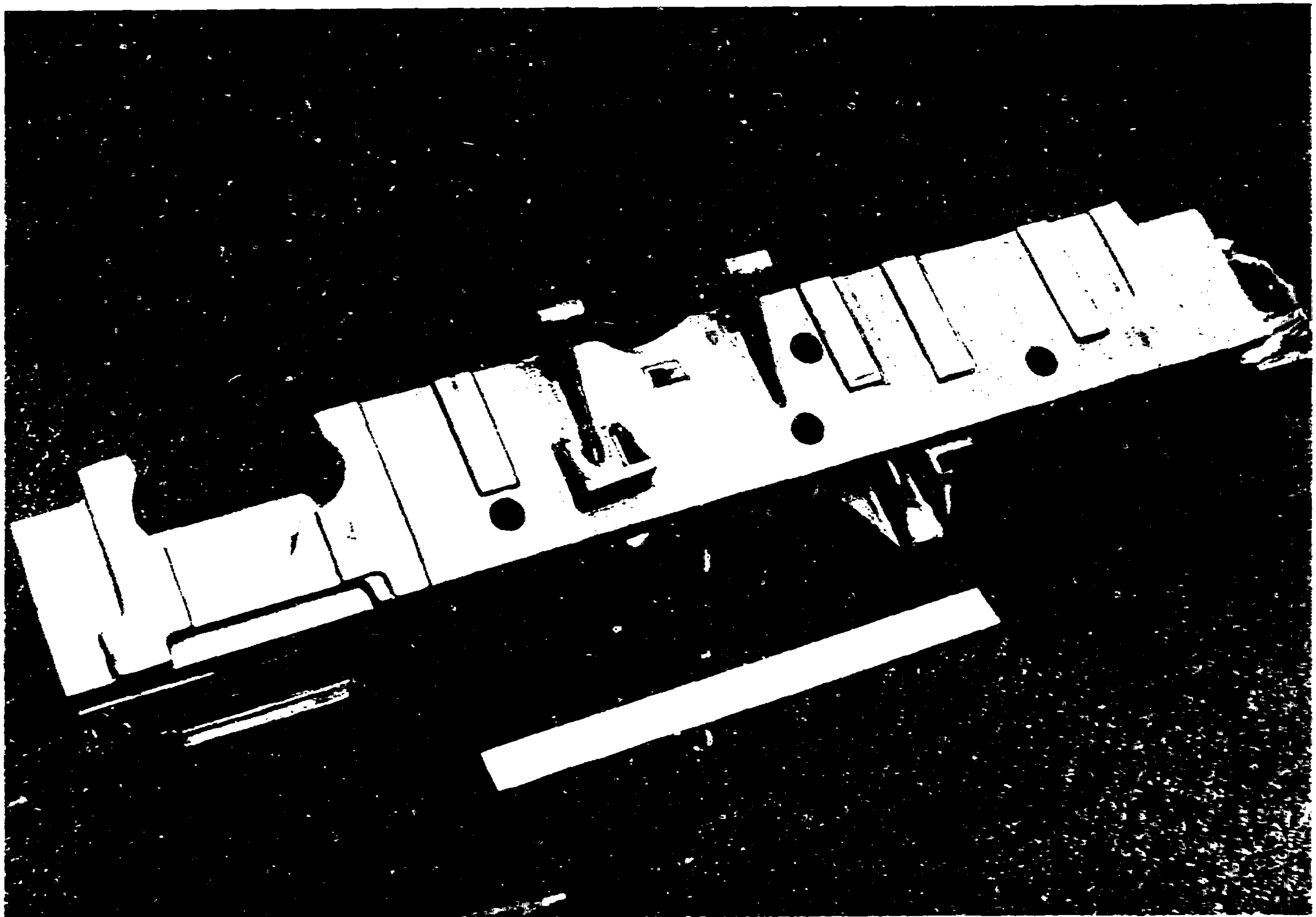
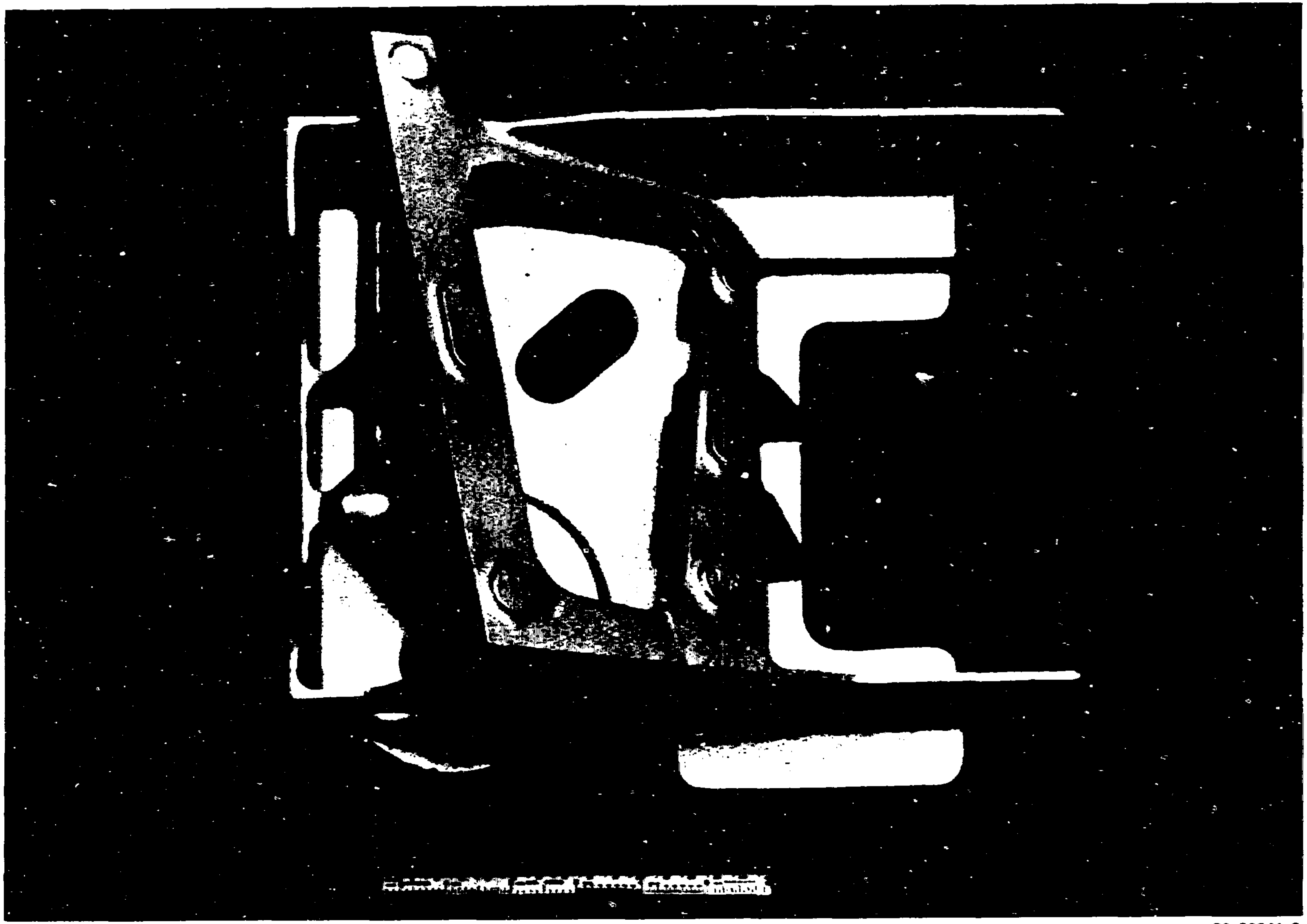


FIGURE 123. CASTING NO. 4, A201 ALLOY



83-01898-3

FIGURE 124. CASTING NO. 5, A201 ALLOY



83-03941-2

FIGURE 125. CASTING NO. 6, A201 ALLOY

Process Variable	Test Method	Acceptance Criteria
Internal Soundness	Radiographic Examination (MIL-STD-00453)	Maximum Defect Not Worse Than Grade B Per MIL-C-6021 1/4" Stds.
Heat Treatment Response	(1) Tensile Properties of Attached Coupon (ASTM B557)	A357-T6: 42-47 ksi YS 51 ksi UTS A201-T7 60 ksi UTS 55 ksi YS
	(2) A201-T7 Electrical Conductivity (MIL-STD-1537)	31% IACS Min.
	(3) Hardness (ASTM E18)	A201-T7: 70HRB Min A357-T6: 90HRB Min
Solidification Rate - DAS Control (A357 Only)	A357-T6 DAS Evaluation Per Proposed Specification	A357-T6 Max DAS Det. by Specification

All castings, regardless of their predicted acceptability, were included in the final tensile property evaluation. When the test results satisfied the acceptance criteria, it was predicted that the tensile properties of the verification castings or specific areas of the casting would at least be equal to the minimum tensile properties specified in the proposed material specification. These property values were as follows:

Material	Properties (UTS-YS-e)
A357-T6	50 ksi - 40 ksi - 3%
A201-T7	60 ksi - 50 ksi - 3%

3. TEST RESULTS AND CONCLUSIONS

a. A357-T6 Castings (Figures 1, 2, and 3)

The acceptance test results of A357-T6 Castings 1, 2, and 3 are discussed below.

(1) Composition (taken from the casting)

Casting	Content, %						
	Si	Mg	Fe	Ti	Be	Mn	Al
No. 1	6.8	0.68	0.05	0.11	0.05	0.02	Remainder
No. 2	6.6	0.66	0.16	0.14	0.06	0.01	"
No. 3	6.7	0.57	0.09	0.16	0.05	0.01	"
Acceptance Limits	6.0 8.0	0.50 0.70	0.20 Max	0.10 0.20	0.04 0.07	0.05 Max	"

All of the compositions were determined to be within the acceptance range for samples taken directly from the casting.

(2) Hardness

Hardness values taken to confirm that the casting was aged to the T6 condition, were as follows: Casting No. 1: 96.3 to 100.0 HRE; No. 2: 94.2 to 96.9 HRE; and No. 3: 92.6 to 95.0 HRE. Since all values exceeded a minimum value of 90 HRE, the material was condisered to be in the T6 condition.

(3) Integral Attached Test Coupon Tensile Properties

Coupons excised from each casting to simulate an integral attached coupon were evaluated for tensile properties. The following results were obtained:

Simulated Attached Coupon Properties

Casting No.	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (%)
1	55	45	12
2	52	(41)	8
3	(46)	(39)	6
Required Minimum	51	42/47	--

( ) Unacceptable value

Casting No. 1 was acceptable; however, Castings No. 2 and No. 3 were not acceptable due to the low values of yield strength and ultimate tensile strength indicated.

Casting No. 2 was given an additional aging of one hour at 330F. A second coupon excised from the casting showed the following tensile properties:

Ultimate tensile strength 52.5 Ksi

Yield strength 44.0 ksi

Elongation 7.4 percent

Since these were acceptable properties for the attached coupon, casting No. 2 remained in the program for further evaluation as a candidate casting which has a capability of meeting minimum tensile properties. Since casting No. 3 did not exhibit minimum coupon properties, it was predicted that the casting would not be capable of meeting minimum specification properties. No further testing was necessary.

(4) Radiographic Quality

Castings Nos. 1 and 2 were radiographically inspected and were judged to be acceptable to Grade B requirements of MIL-C-6021, which limits the size and severity of defects to Plate No. 1 of ASTM radiographic standards of ASTM E155.

(5) DAS

DAS measurements were made on the surface of various areas of Casting Nos 1 and 2. Areas of smallest and largest DAS were selected to simulate the attached coupons.

DAS and tensile property values from test sites that were used to simulate the attached coupons were as follows:

Casting	Test Site Area, DAS	DAS Values (inch)	Tensile Properties UTS (Ksi)	YS (Ksi)	e (%)
1	Small	0.0010	53.9	44.8	9.0
1	Large	0.0017	5C.8	42.4	6.5
2	Small	0.0008	52.5	42.0	13.1
2	Large	0.0020	47.3	40.5	3.7

The calculated maximum DAS for the minimum tensile ultimate strength of 50 Ksi was determined in the manner specified in the proposed specification AMS XXXX included in Appendix H.

$$DAS_{max} = \left(\frac{DAS_2 - DAS_1}{UTS_1 - UTS_2}\right)(UTS_1 - UTS_3) + DAS_1$$

Where:

DAS_{max} = Maximum size DAS acceptable to meet minimum tensile properties (1×10^{-4} inches)

UTS_1 = Ultimate tensile strength of the attached coupon with smallest DAS (ksi)

UTS_2 = Ultimate tensile strength of the attached coupon with largest DAS (ksi)

UTS_3 = Ultimate tensile strength minimum required (ksi)

DAS_1 = Size of DAS of coupon with smallest structure (1×10^{-4} inches)

DAS_2 = Size of DAS of coupon with largest structure (1×10^{-4} inches)

The maximum permissible DAS of casting No.1 was:

$$DAS_{max} = \frac{17-10}{53.9-50.8}(53.9-50) + 10 = \frac{7}{3.1}(3.9) + 10 = 18.8 \times 10^{-4} \text{ inch}$$

The maximum permissible DAS of casting No. 2 was:

$$DAS_{max} = \frac{20-8}{52.5-47.3}(52.5-50) + 8 = \frac{12}{5.2}(2.5) + 8 = 13.8 \times 10^{-4} \text{ inch}$$

The DAS of various test sites on each casting were as follows:

Casting	Test Site Location	DAS (1×10^{-4}) inches	Maximum Permissible DAS (1×10^{-4} inches)
1	1	0.0009	0.0018
1	2	0.0013	0.0018
1	3	0.0011	0.0018
1	4	0.0010	0.0018
2	1	0.0009	0.0013
2	2	0.0011	0.0013
2	3	0.0010	0.0013

(6) Prediction of Casting Capability

The findings indicate that both castings 1 and 2 show a capability of meeting the minimum ultimate strength of 50 ksi yield strength of 40 ksi and elongation of 3%, while casting Number 3 does not show a similar capability of exhibiting these properties.

(7) Casting Tensile Properties Determination

Tensile specimens excised from each casting exhibited the following properties:

Casting	Test Site	Tensile Properties UTS (Ksi)	YS (Ksi)	e (%)
1	1	53.4	42.9	11.5
1	2	52.0	42.2	8.0
1	3	52.6	42.7	8.0
1	4	53.7	44.7	7.5
2	1	52.2	40.8	12.0
2	2	51.9	41.6	9.2
2	3	53.2	42.3	13.2
3	1	46.0	39.0	6.0
3	2	46.5	38.7	5.6
3	3	46.5	37.8	3.4
3	4	48.6	39.8	6.1
3	5	48.6	39.7	5.8

(8) Conclusions

These results demonstrate the following:

(a) The prediction that casting 1 and 2 had the capability of meeting minimum tensile strength properties of 50 Ksi UTS, 40 Ksi YS and 3% elongation was correct.

(b) The strength properties of casting 3 were correctly predicted to be incapable of exhibiting minimum strength properties of 50 Ksi UTS, 40 Ksi YS, and 3% elongation.

(c) The validity of the QAA procedures and criteria was demonstrated to apply to A357-T6 casting configurations procured for flight hardware.

b. A201-T7 Castings (Figures 4, 5, and 6)

Castings 4, 5, and 6 of A201-T7 were subjected to QAA tests proposed in AMS material specification for A201-T7 aircraft structural casting procurement in Appendix H. Results of the tests are discussed below.

(1) Composition (taken from the casting)

Casting Number	Cu (%)	Fe (%)	Si (%)	Mg (%)	Ti (%)	Ag (%)	Mn (%)	Al (%)
4	4.91	0.08	0.02	0.23	0.25	0.71	0.29	Remainder
5	4.89	0.09	0.04	0.35	0.18	0.60	0.34	Remainder
6	4.26	0.05	0.02	0.20	0.33	0.50	0.30	Remainder
Acceptance Limits	4.0 / 5.5	0.05 Max.	0.05 Max.	0.20 / 0.40	0.15 / 0.35	0.50 / 1.0	0.20 / 0.50	

The composition of the castings was considered acceptable for further evaluation although the values of 0.08 and 0.09 for iron (Fe) exceeded the acceptance limit.

(2) Hardness and Conductivity

Results of the hardness and conductivity tests were used to confirm that the castings were overaged to the T7 condition. The following values were obtained:

Casting	Hardness (HRB)	Electrical Conductivity (% IACS)
No. 4	61.0 to 72.7	31.5 to 32.7
No. 5	70.2 to 75.2	29.8 to 31.5
No. 6	68.2 to 76.7	31.0 to 32.0
Proposed Minimum	70.0	31.0

The results were tentatively accepted pending determination of tensile properties from an integral coupon.

(3) Radiographic Quality

Radiographic examination of each casting indicated that the quality varied as follows:

Casting No.	
4	Grade B and C
5	Grade B, C, and D
6	Grade B

The castings were accepted for further evaluation, based on the existence of Grade B areas, for use in predicting casting tensile property capability.

(4) Integrally Attached Coupons

Since attached coupons were not available, an excised coupon was tested. The results were as follows:

Casting Number	Ultimate Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (%)
4	64.3	56.7	9.8
5	60.4	58.2	2.7
6	59.4	48.1	9.9
Proposed Minimum	60.0	55.0	(Not Required)

Since the test coupon of Casting 6 did not meet the minimum yield strength of 55 ksi or ultimate strength of 60 ksi, the casting was judged to not be capable of meeting minimum tensile properties required by specification and therefore further QAA testing was not required.

(5) Prediction of Casting Capability

Castings 4 and 5 satisfactorily met the minimum QAA requirements proposed for casting acceptance and therefore more predicted to be capable of meeting minimum tensile properties of 60 ksi UTS, 50 ksi YS and 3% elongation. Casting 6 was predicted to not be capable of meeting these properties.

(6) Casting Tensile Property Determination

The tensile coupons excised from the castings exhibited the following tensile properties:

Casting No.	Test Sites	Ultimate Tensile Strength (Ksi)	Yield Strength (Ksi)	Elongation (%)
4	1	61.4	54.8	10.8
	2	64.3	56.7	9.8
	3	66.7	61.2	4.3
	4	65.7	60.6	4.7

Casting No.	Test Sites	Ultimate Tensile Strength (Ksi)	Yield Strength (Ksi)	Elongation (%)
5	1	63.1	59.1	3.9
	2	62.1	58.7	3.4
	3	61.9	56.5	5.6
6	1	58.2	47.1	5.4
	2	56.3	46.2	8.7
Minimum Specification		60.0	50.0	3%

(7) Conclusions

(a) These test results demonstrated that when the casting met the QAA criteria, the casting was capable of meeting the minimum specification tensile property requirements.

(b) The validity of the QAA procedures and criteria was demonstrated to apply to A201-T7 casting configurations procured for flight hardware.

SECTION XI
COST ANALYSIS

Casting is the simplest and most direct method of producing a complex shape. Molten metal is transformed directly into the desired shape without requiring additional forming operations which means that castings are an economical method of production. However, when simple configurations are required for the final form, other production methods such as rolling, extruding, drawing, forging, or forming may be more economical. Conversely, the more complex the configuration, the higher the probability that a casting will be more economical. A study of several configurations was made to demonstrate the effect of part complexity on the cost benefit derived from casting methodology.

1. SIMPLE DESIGN - LEADING EDGE EXTENSION (LEX)

The leading edge extension (LEX) is a primary structural member of the wing leading edge assembly structures (Figure 126). The upper skin and support structure are of 7075-T7351 three-inch aluminum alloy plate stock. The lower skin is attached by means of standard rivets and fasteners.

a. Alternate Designs

Three casting design alternatives appear feasible for the LEX. Design No. 1 (Figure 127) uses an open framework casting with separately [illegible]hed sheet metal upper and lower skins. This design ensures a producible-low-cost casting, but it requires the manufacture and installation of upper and lower skins. Design No. 2 (Figure 128) is a modification of Design No 1. In Design No. 2, the body frame and upper skin are cast together. The separately produced lower skin is later blind-bolted to the cast structure. Neither of these designs reflect a cost improvement over the hogged-out design.

Design No. 3, the most feasible of the three casting concepts, which is well within today's technological state-of-the-art, is a single piece

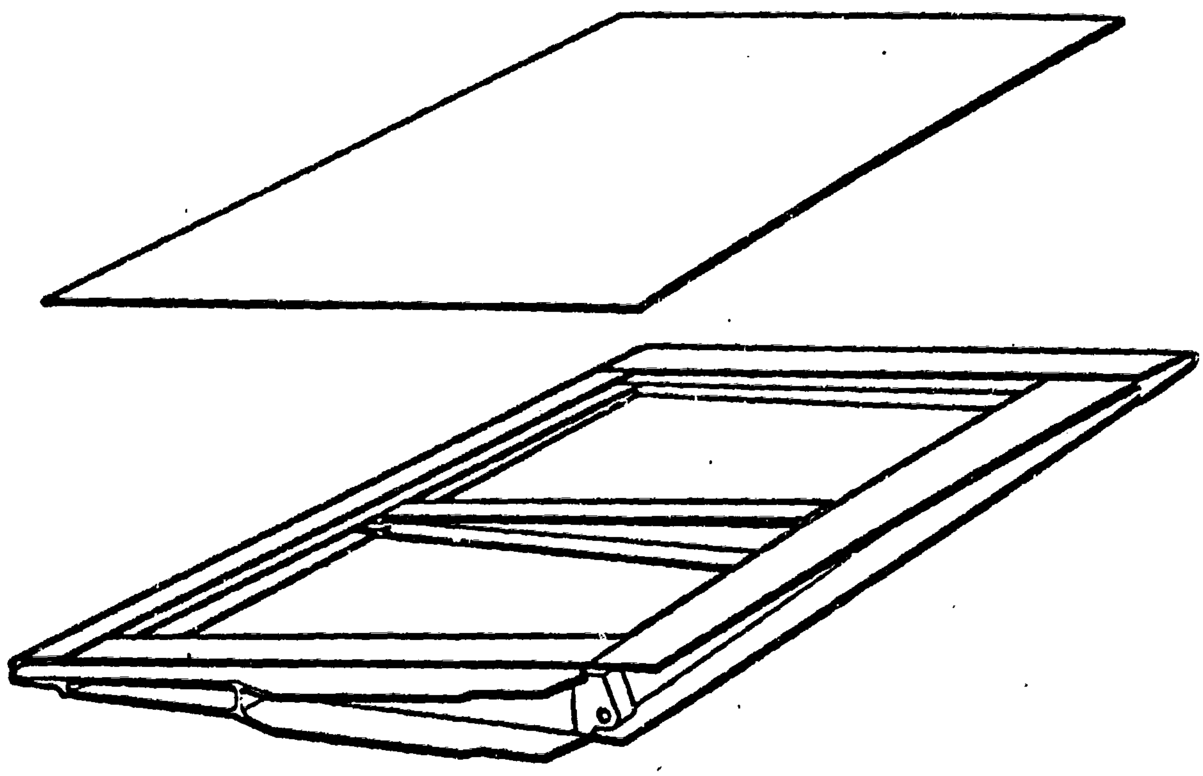


FIGURE 126. LEADING EDGE EXTENSION HOGOUT DESIGN WITH ASSEMBLED DETAILS

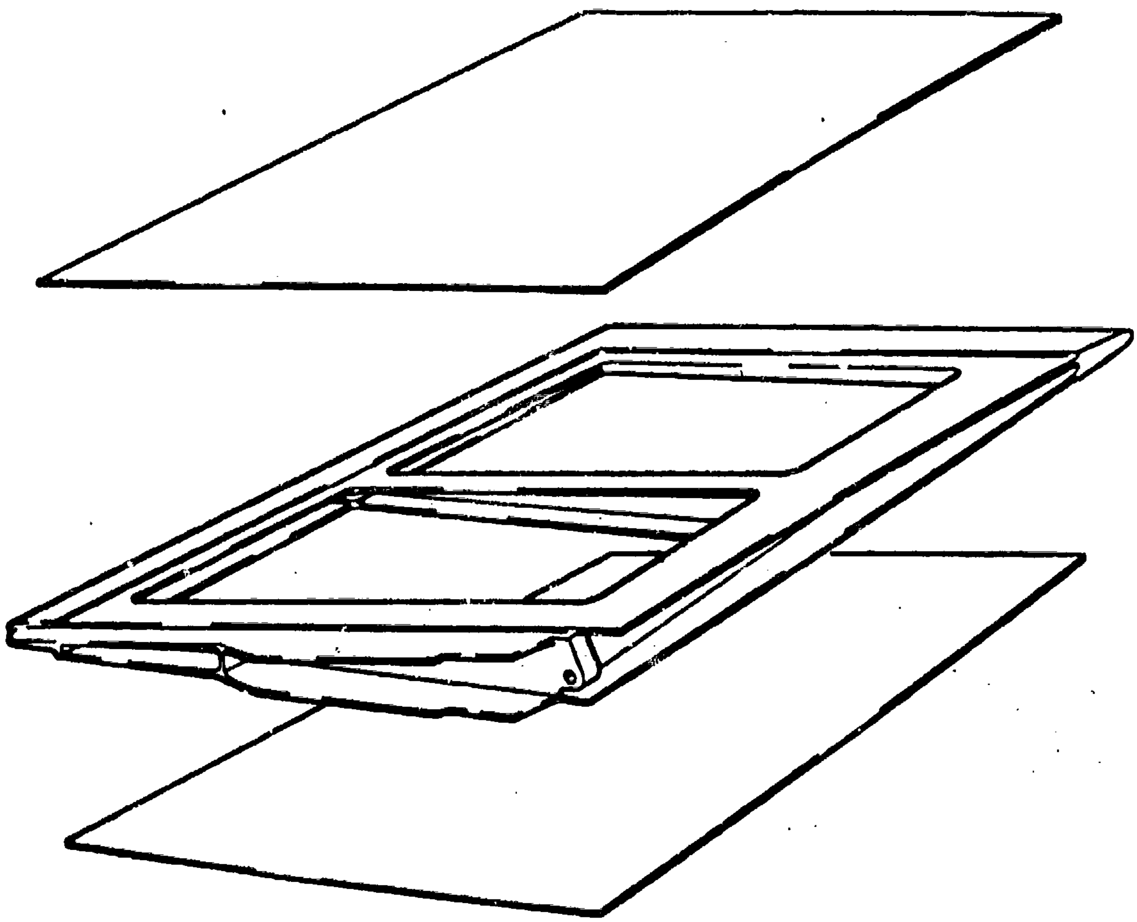


FIGURE 127. LEADING EDGE EXTENSION CASTING DESIGN ALTERNATE NO. 1: FRAMEWORK ONLY, SEPARATE UPPER AND LOWER ATTACHED SKINS

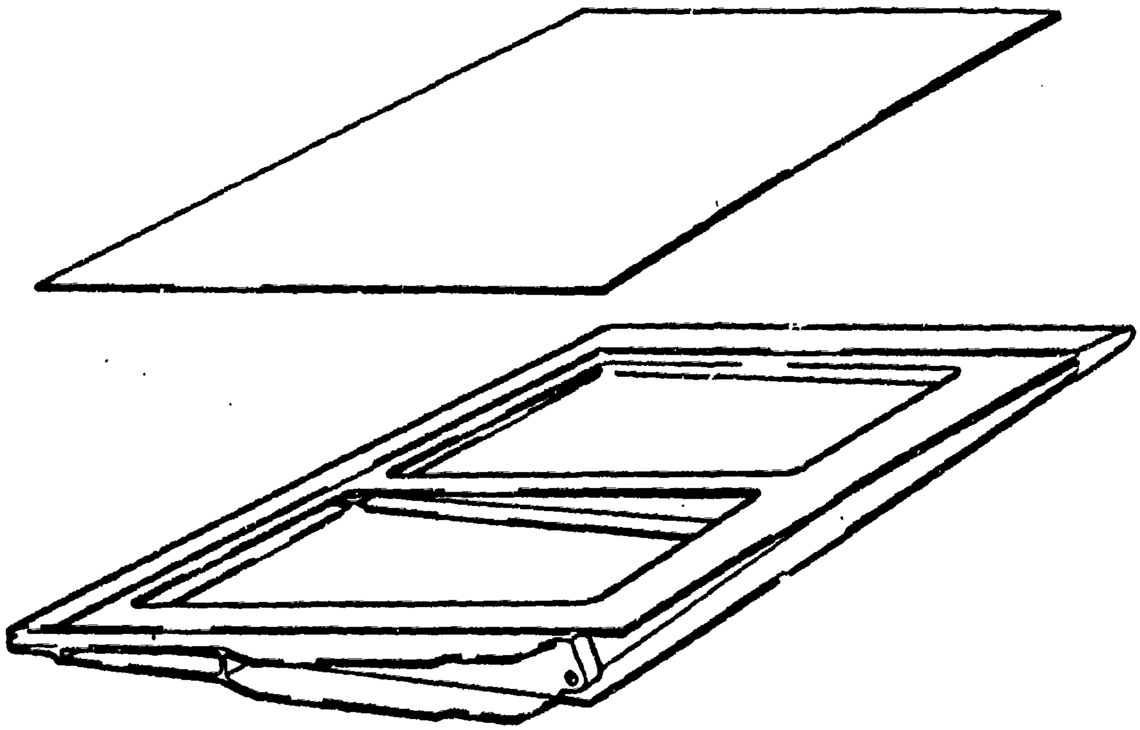


FIGURE 128. LEADING EDGE EXTENSION CASTING DESIGN ALTERNATE NO. 2: FRAMEWORK PLUS UPPER ML SKIN SEPARATE LOWER ATTACHED SKIN

casting (Figure 129). This design ostensibly circumvents most of the machining that is required on the existing hogged-out design, presumably with a resulting reduction in costs. However the much higher cost of the single piece casting causes the total cost to be higher than the actual cost for the hogged-out design.

As a single cast component, the high cost of the LEX casting, plus the advantage of multiple spindle machining of the hog-out gives the hog-out design an economic edge.

It is significant to note that simple concepts, such as the LEX, involving the casting process may not always be cost competitive. Each design must be studied for both technical and economic advantages before the design is released as a casting.

b. LEX Estimated Costs, (1982 Dollars):

Following are comparisons of costs estimated for the hog-out design and candidate casting designs:

Non-recurring Estimated Costs:

$148,000	Mechanical Hog-out and Buildup Design
240,000	Cast Frame, Buildup Using Weldbonded Skins
351,000	Cast Frame and Upper Skin Separate Lower Skin
246,000	Single-Piece Casting Design

Recurring Estimated Costs, Hog-out and Buildup Design:

$ 66,130	10 Shipsets
287,500	50 Shipsets
499,200	100 Shipsets
1,844,500	500 Shipsets

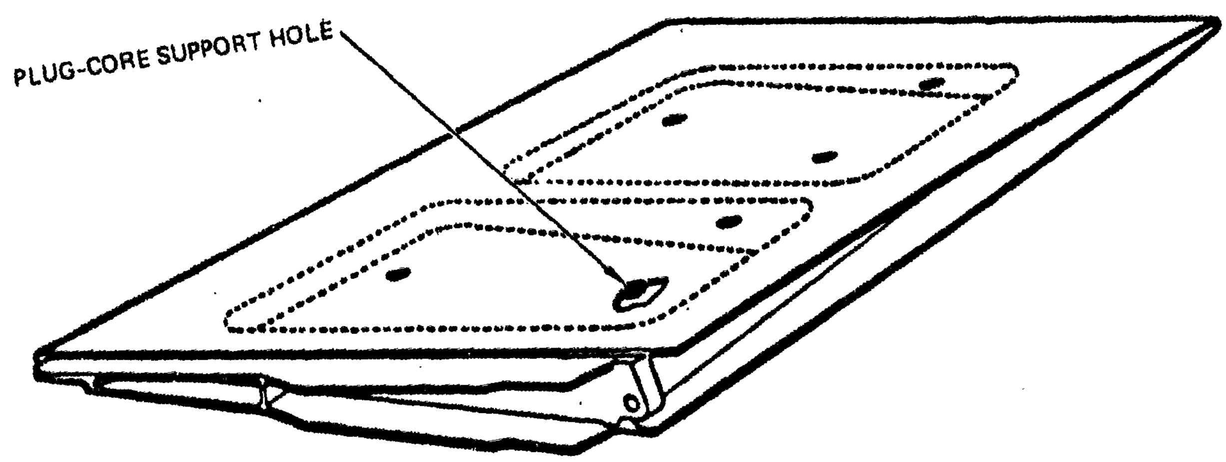


FIGURE 129. LEADING EDGE EXTENSION CASTING DESIGN ALTERNATE NO. 3:
SINGLE PIECE, INTEGRAL CAST SKINS

Recurring Estimated Costs, Alternate Design No. 1: Cast Frame and Separate Skins:

$ 61,820	10 Shipsets
255,150	50 Shipsets
472,400	100 Shipsets
2,019,500	500 Shipsets

Recurring Estimated Costs, Alternate Design No. 2: Premium Cast Frame and Upper Skin:

$ 81,690	10 Shipsets
310,500	50 Shipsets
607,200	100 Shipsets
2,909,000	500 Shipsets

Recurring Estimated Costs Alternate Design No. 3: Single Piece Castings

$ 72,540	10 Shipsets
339,400	50 Shipsets
661,300	100 Shipsets
3,139,500	500 Shipsets

c. Conclusion

Three designs employing use of castings were evaluated against the conventional hog-out and buildup design. The evaluation indicated that none of these designs could compete economically with the hog-out version.

2. SEMI-COMPLEX DESIGN - CANOPY MECHANISM SUPPORT

The canopy mechanism support is an assembly produced from a number of machined and otherwise fabricated detail parts (Figures 130 and 131). Parts are prefitted together and then welded to one another to produce the assembly. Extensive machining is required after welding.

a. Alternate Casting Design

In the cast version (Figure 132), all of the noted detail components shown in Figure 130 are integrated into a single casting. The casting is finish-machined to final configuration requirements in the attachment areas.

Estimated costs for the build-up design and casting design are compared below:

b. Estimated costs (1982 Dollars)

Non-recurring Estimated Costs:

$ 235,000	Buildup and Welded Design
191,000	A357-T6 Casting Design

Recurring Estimated Costs, Buildup and Welded Design:

$ 86,000	10 Shipsets
291,000	50 Shipsets
491,000	100 Shipsets
1,686,000	500 Shipsets

Recurring Estimated Costs, Casting Design:

$ 44,000	10 Shipsets
195,000	50 Shipsets
370,000	100 Shipsets
1,426,000	500 Shipsets

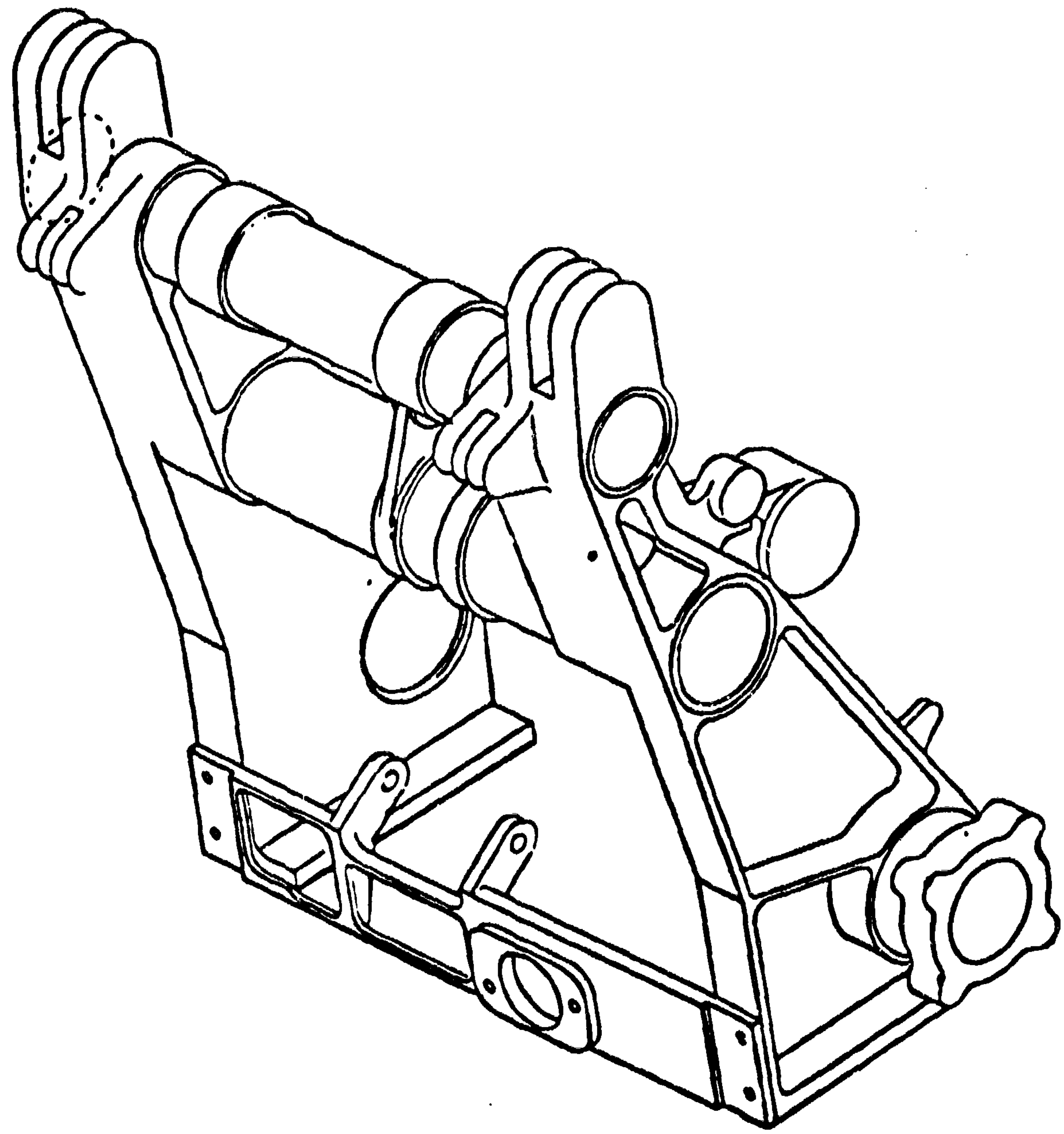


FIGURE 130. SUPPORT CANOPY MECHANISM ASSEMBLY, DETAIL BUILDUP DESIGN

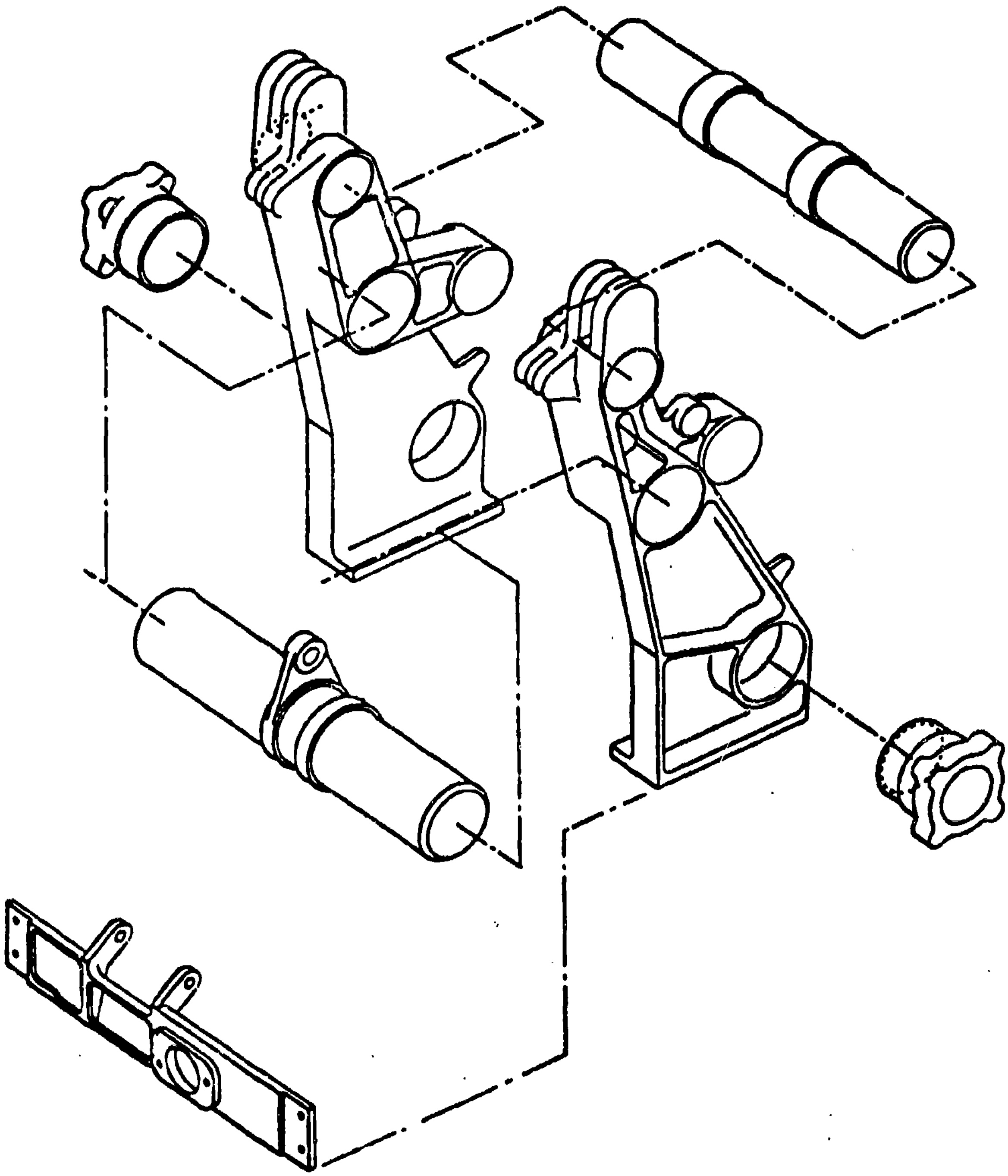


FIGURE 131. SUPPORT CANOPY MECHANISM, EXPLODED VIEW, DETAIL BUILDUP DESIGN

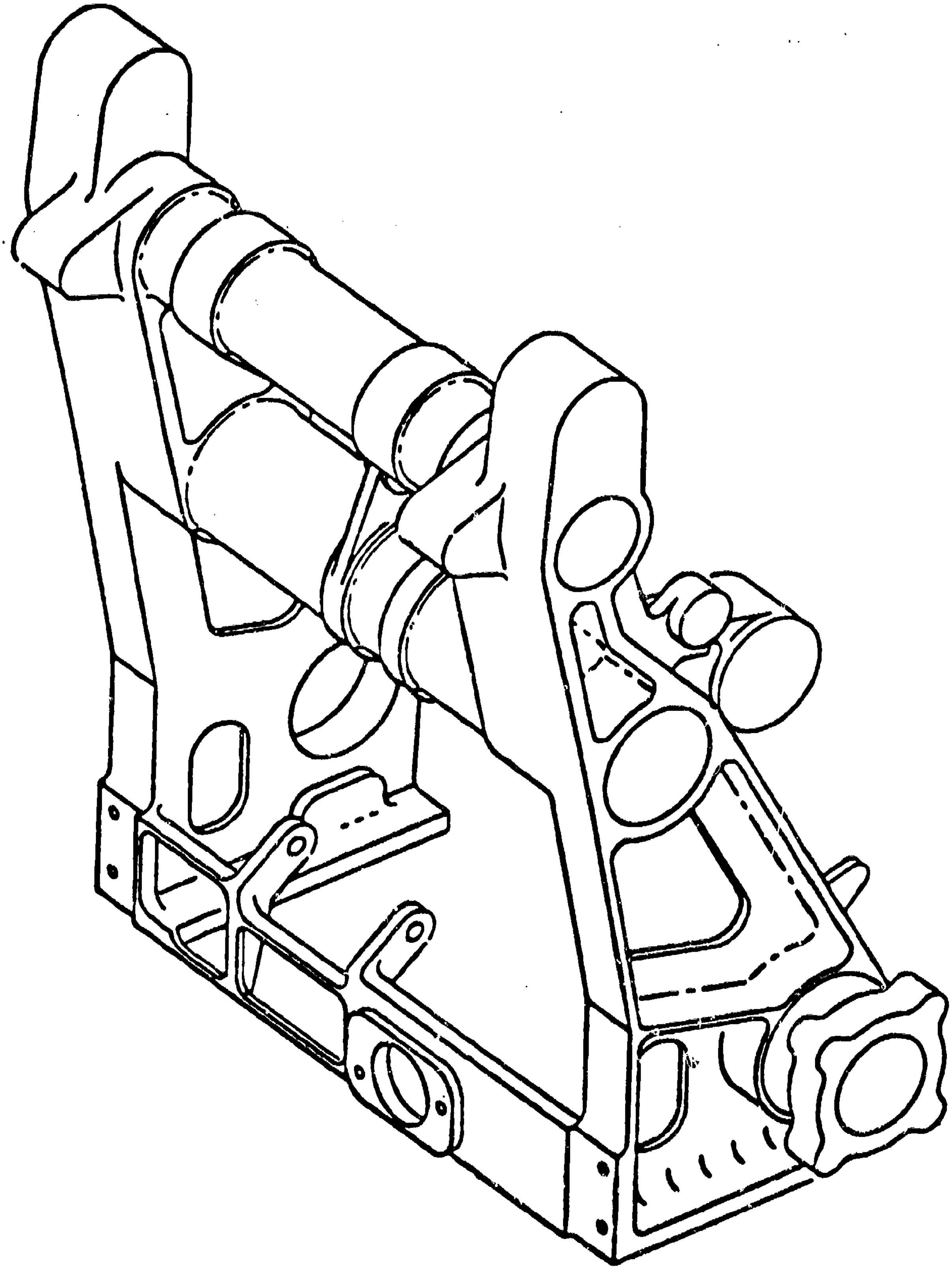


FIGURE 132. SUPPORT CANOPY MECHANISM, CASTING DESIGN

C. Estimated Savings

The evaluation demonstrated that the casting design offers a significant reduction in costs as follows:

$235,000 - $191,000 = $44,000 Non-recurring Savings,

$1,686,000 - $1,426,000 = $260,000 Recurring Savings (500 Shipsets)

$260,000 divided by 500 Shipsets = $520.00 Savings Per Shipset

3. COMPLEX DESIGN - PYLON, FUSELAGE CENTER LINE, 30mm GUN

The current 30mm gun pylon is designed to be machined from a 7075 aluminum alloy hand forging as shown in Figure 133. The size of this forging is approximately 11 by 12 by 110 inches and weight is approximately 1450 pounds. Forgings are rough machined down to a predetermined cross sectional thickness, then heat treated prior to finish-machining. Full hog-out machining of hand forgings of this size into a complex pylon structure is extremely difficult, time consuming, and costly.

a. Alternate Casting Design

Adoption of the three-piece A357 and A201 aluminum alloy sand casting design (Figure 134) would result in an estimated cost avoidance of $4 million over a 500-ship program.

b. Estimated Costs, (1982 Dollars):

Hog-out and casting design estimated costs are compared below:

Non-recurring Estimated Costs:

$ 695,000	Hog-out Design (Single-Piece Hand Forging)
923,000	A357-T6 and A201 Casting Design Three Castings Plus Assembly)

Recurring Estimated Costs, Existing Hog-out Design:

$ 181,340	10 Shipsets
774,950	50 Shipsets
1,503,400	100 Shipsets
7,517,000	500 Shipsets

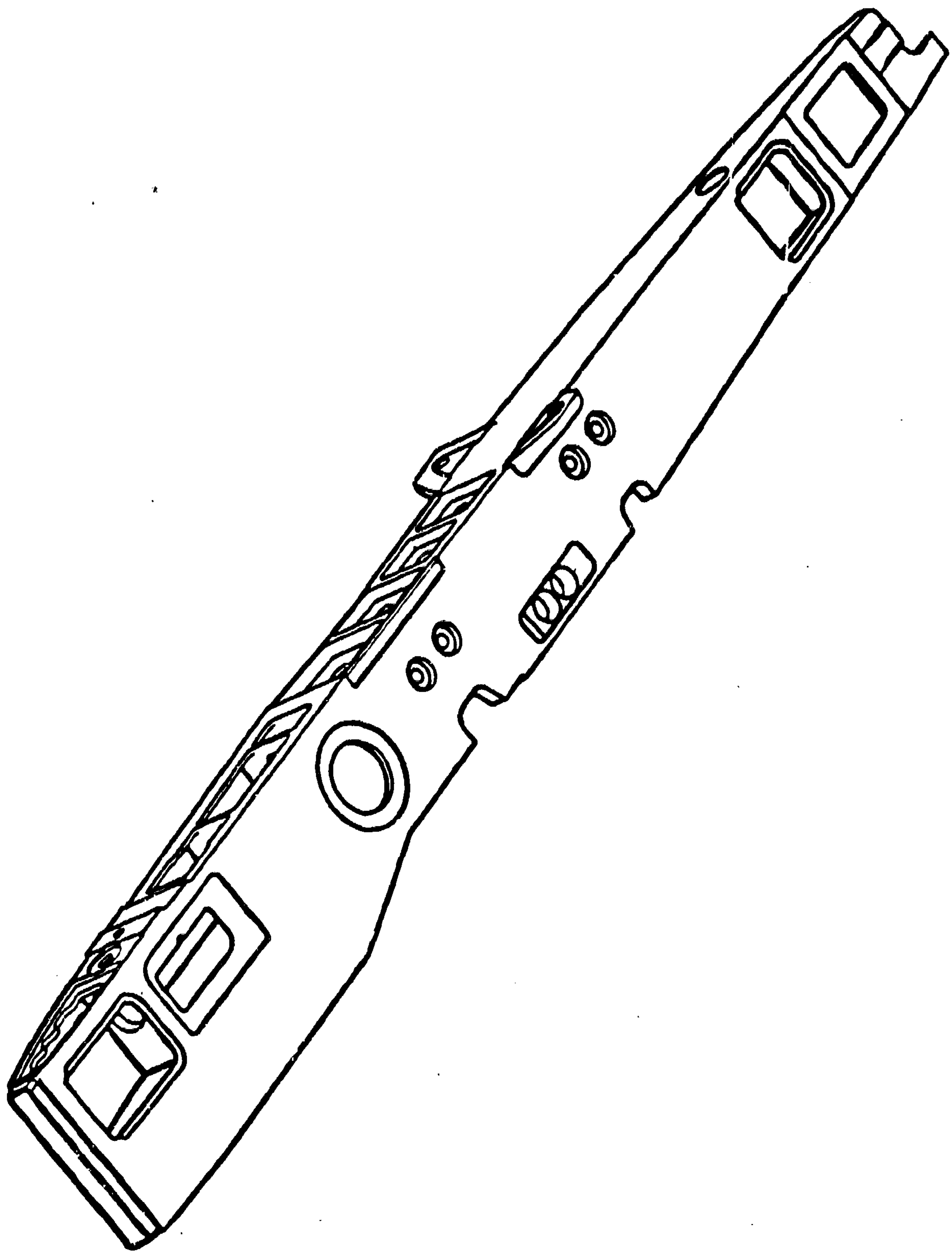


FIGURE 133. PYLON ASSEMBLY, MACHINE HOGOUT DESIGN, 7075 HAND FORGING

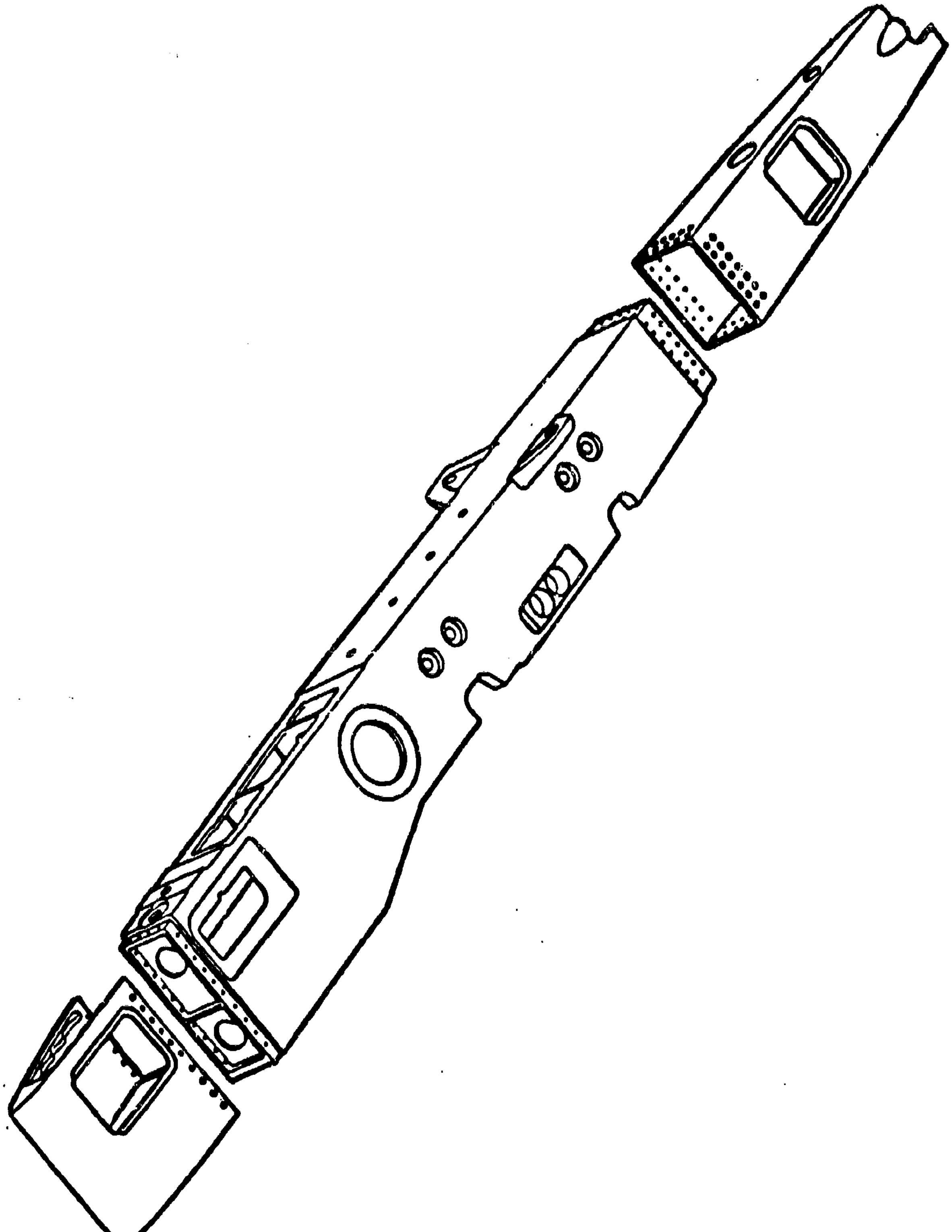


FIGURE 134. PYLON ASSEMBLY, CASTING DESIGN, THREE SECTIONS: CENTER SECTION A201 ALLOY, END SECTIONS A357 ALLOY —

Recurring Estimated Costs, Proposed Three-Piece Casting Design:

$ 121,200	10 Shipsets
455,000	50 Shipsets
797,000	100 Shipsets
2,910,000	500 Shipsets

c. Estimated Savings

Computations of the estimated savings of the proposed casting design are presented below:

$7,517,000 - $2,910,000 = $4,607,000 Delta Recurring Cost Savings.

$4,607,000 divided by 500 Shipsets = $9,214 Average Shipset Savings

$228,000 Implementation Cost, Casting Program divided by $9,214 = 25 Shipsets (Breakeven or Return on Investment Point).

4. COMPLEX DESIGN (VERTICAL STABILIZER)

The current vertical assembly structure shown in Figure 135 is a 63-piece aircraft structure that requires many assembly operation steps and has compatibility problems associated with integrating a large aluminum substructure to advanced graphite composite structural skins. Compatibility problems occur due to fasteners and differences in thermal coefficients of expansion.

a. Alternate Casting Design

The alternate casting design shown in Figure 136 is a much less complex assembly. It is composed primarily of a single sand casting, with weld-bonded sheet metal aluminum skins. The weld-bonding of the sheet metal skins to the main casting creates an integral, sealed fuel vent cavity and eliminates the separate fuel vent stand pipe. The weld-bond technique used on the cast vertical assembly structure also avoids problems associated with maintaining consistent quality on the drilling of many precision holes and the installation of a large number of fasteners.

It is estimated that changeover from the current buildup design to the casting design would result in an approximate 29-pound weight savings per aircraft. Most importantly, these savings would be realized in the aft section of the aircraft.

From a financial standpoint, the advantages of a casting design appear to be significant. Implementation costs for the casting design are estimated to be $2.5 million. Crossover point before pay back of implementation costs ($2.5 million) is estimated to be at approximately the 113th unit. It is estimated that a net cost avoidance of approximately $8.6 million could be realized on a program of 500 shipsets using the proposed casting design.

The preceding statements relate to the buildup conventional substructure design already released. If the original design had been the casting concept, as described in this report, it is estimated that an additional $3.5 million in non-recurring costs could have been realized.

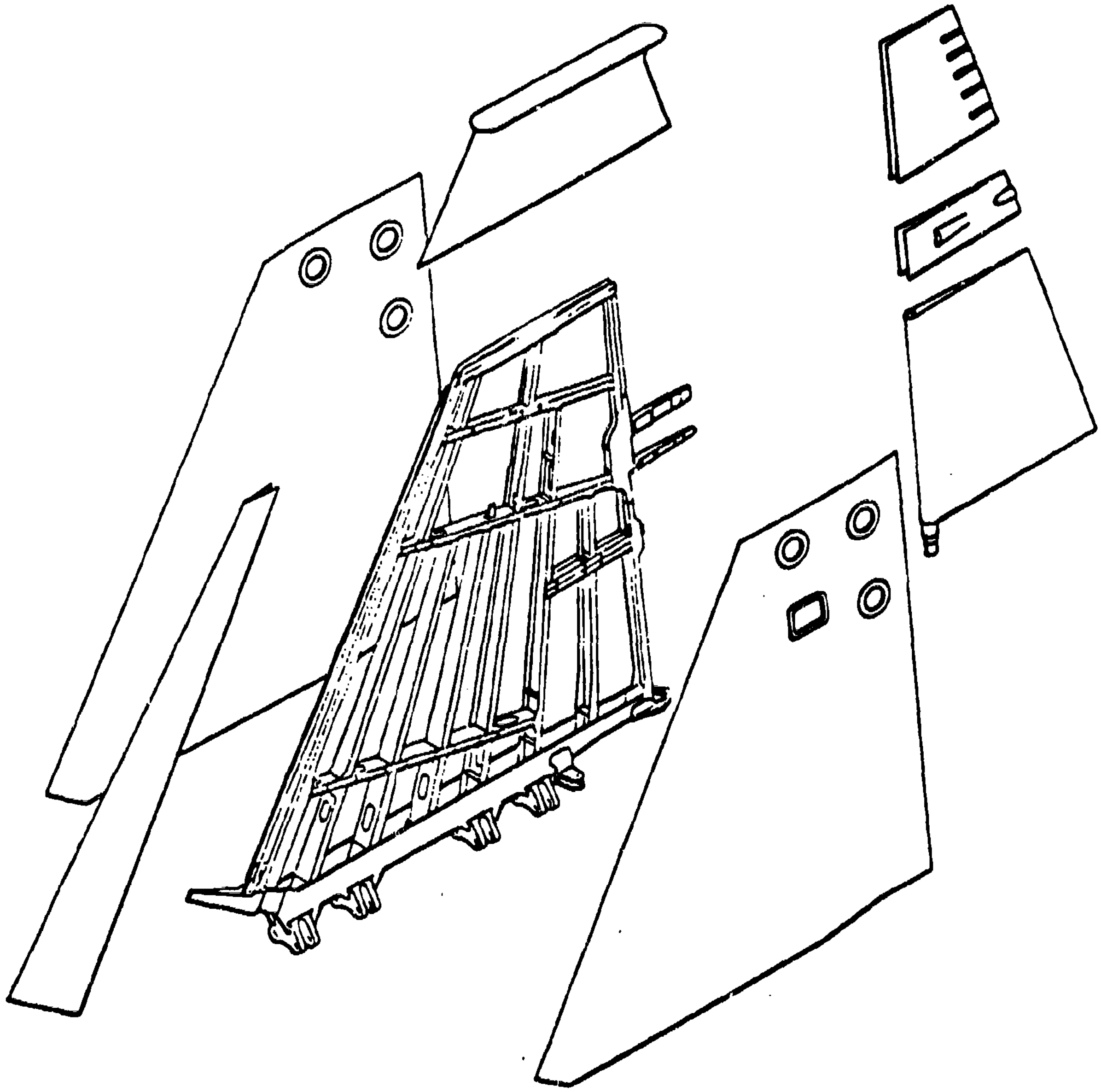


FIGURE 135. VERTICAL STABILIZER BUILDUP DESIGN AND ATTACHING STRUCTURES

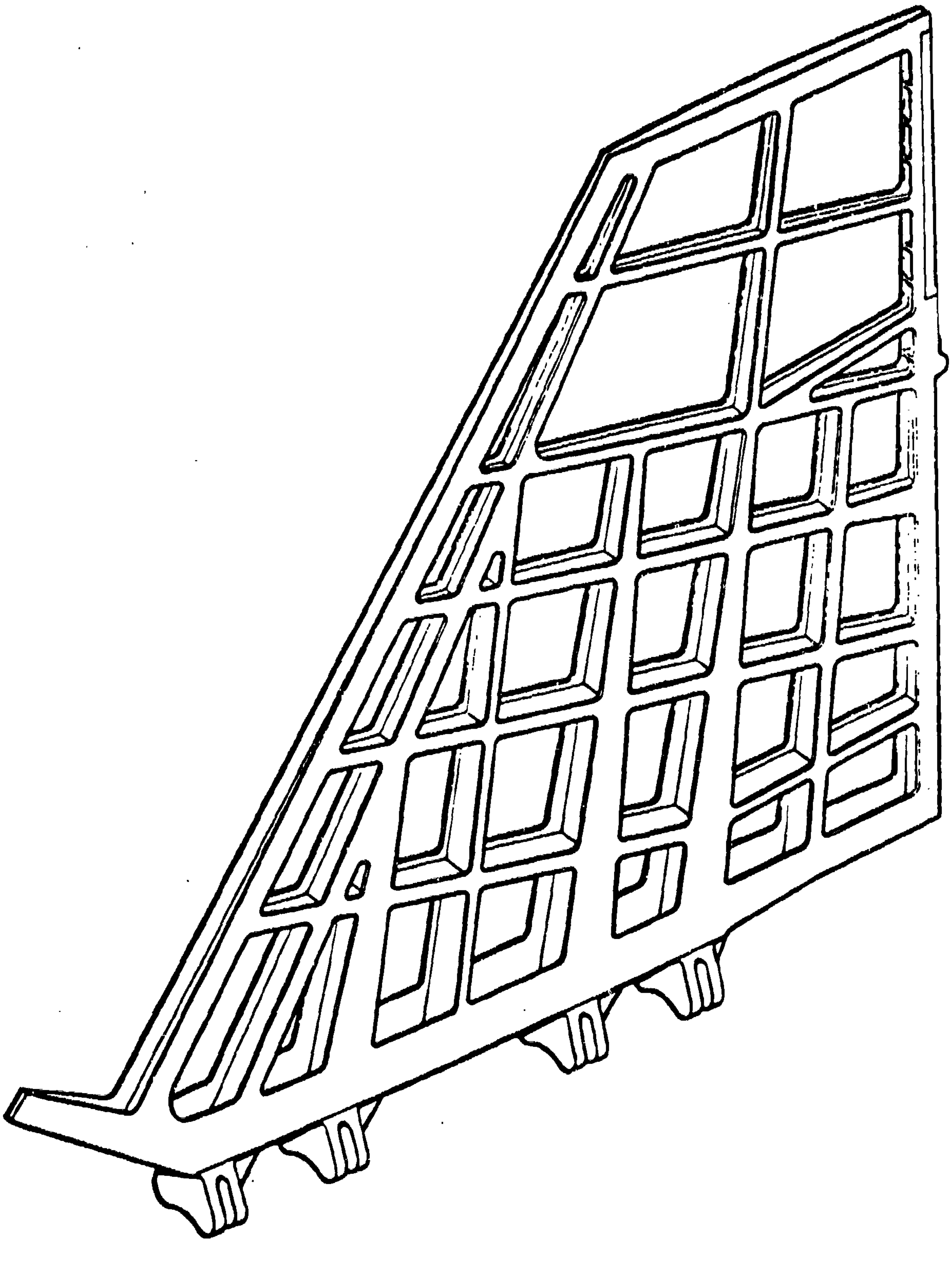


FIGURE 136. VERTICAL STABILIZER, CASTING DESIGN

b. Estimated Costs (1982 Dollars):

Buildup and casting design estimated costs are compared below:

Non-recurring Estimated Costs:

$6,000,000	Conventional Buildup Design
2,500,000	Alternate Casting Design

Recurring Estimated Costs, Existing Buildup Design:

$ 674,000	10 Shipsets
2,765,000	50 Shipsets
4,660,000	100 Shipsets
15,470,000	500 Shipsets

Recurring Estimated Costs, Proposed Casting Design:

$ 188,000	10 Shipsets
771,500	50 Shipsets
1,298,500	100 Shipsets
4,315,000	500 Shipsets

c. Standard Savings

Summations of the estimated savings of the proposed casting design are presented below:

$15,470,000 - $4,315,000 = $11,155,000 Delta Difference (Recurring Cost Savings 500 Shipsets)

$11,155,000 divided by 500 Shipsets = $22,310 Average Shipset Savings

$11,155,000 Recurring Savings (500 SS) - $2,500,000 Implementation Costs = $8,655,000 Net Savings

$2,500,000 Implementation Cost, Casting Program divided by $22,310 = 113 Shipsets (Crossover Point)

SECTION XII
CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

The objectives of this program were accomplished by the development of the following:

1. Design property information was developed and approved by the MIL-HDBK-5 Committee.

2. Specifications and quality assurance acceptance criteria were developed which will eliminate the need for casting factors in the design of structural aircraft quality aluminum castings.

3. The cost effectiveness of aluminum castings was demonstrated using simple, semi-complex and complex configurations.

In addition, specific conclusions regarding the following were possible

1. The foundry manufacturing process variables which must be controlled to produce castings of consistent mechanical properties are (1) melt composition, gas content, grain refinement, and metal temperature, (2) mold materials and their placement, gating and risering system, and (3) heat treatment temperature and times, load density and quenching procedures.

2. The metallurgical qualities of the casting which control the mechanical property capability and are affected by the foundry process are (1) radiographic quality, (2) microstructure refinement (DAS - A356 and A357 or Grain Size - A201) and (3) heat treat response capability.

3. By controlling the manufacturing process variables and thereby establishing the necessary casting quality, tensile properties of 50 ksi UTS, 40 ksi YS, and 3 percent elongation in A357-T6 and 60 ksi UTS, 50 ksi YS, and 3 percent elongation in A201-T7 can be consistently produced.

4. The application of proposed Quality Assurance acceptance test criteria will successfully identify configurations of each alloy which meet minimum tensile property requriements.

5. The notched fatigue endurance limit of A357-T6 and A201-T7 structural aircraft quality cast material was comparable to 7075-T73 wrought products.

6. The fracture toughness of A357-T6 structural aircraft quality cast material was comparable to 7075-T751 3" plate, however, the average fracture toughness value of A201-77 was slightly higher.

7. The resistance to fatigue crack propagation of A357-T6 and A201-T7 structural aircraft quality cast material is slightly inferior to wrought aluminum 2124-T851 at higher Δ k values but is comparable at lower Δ k values.

8. Notched fatigue and tensile strength properties of A357-T6 and A201-T7 cast material are more severely affected by poor radiographic quality than fracture toughness.

9. The use of weld metal to restore the quality of A357-T6 and A201-T7 castings was successfully demonstrated. The tensile and fracture toughness properties of the welded material were equal to or better than those of the parent metal. The notched fatigue results were inconclusive.

10. Castings are most likely to be cost-effective in semi-complex or complex configurations.

2. RECOMMENDATIONS

The following is recommended:

1. Additional damage tolerance information is needed for aircraft structural design considerations.

2. Additional tensile data from A201-T7 castings procured to the proposed AMS specification are needed to establish A and B design allowables for MIL-HDBK-5.

3. NDI procedures need to be improved to evaluate radiographic quality of castings with all thicknesses exceeding 1/2 inch.

APPENDIX A

FOUNDRY SURVEY
(SUMMARY).

OBJECTIVE: To establish current level of technology.

SPECIAL AREAS OF INTEREST:

- Tensile property capability of alloy/process
- Foundry equipment, tests, and documentation required for process control
- Recommended QA testing to assure user confidence
- Recommended user survey and first article procedures
- Problem areas related to user procurement practice
- Recommended process variables which need more evaluation to improve tensile property reliability
- Design producibility limitations of alloy and process
- Specification changes recommended for MIL-A-21180

FOUNDRIES SURVEYED

NAME/LOCATION	Alloys Poured to MIL-A-21180 Requirements				
	A356	A357	A201	A206	C355
INVESTMENT PROCESS:					
Rex Precision Products, Inc. Gardena, CA	X	—	—	—	—
Golden State Port Hueneme, CA	X	X	X	—	X
Sigma Castings Corp. City of Industry, CA	X	X	X	X	X
Arwood Corporation Tilton, NH	X	X	X	—	X
Cercast, Inc. Montreal, Canada	X	X	X	X	—
Hemet Casting Co. Hemet, CA	X	X	—	—	X
Anacast Fort Worth, TX	X	—	—	—	—

FOUNDRIES SURVEYED

NAME/LOCATION	A356	A357	A201	A206	C355
	Alloys Poured to MIL-A-21180 Requirements				
SAND COMPOSITE PROCESS					
V&W Castings Bell Gardens, CA	X	X	—	X	X
Hollywood Alloy Compton, CA	X	X	X	—	—
Magnesium Alloy Products Compton, CA	X	X	X	—	—
Alcoa Corona, CA	X	X	—	—	—
Wellman Dynamics Creston, IA	X	X	—	—	—
Hitchcock Industries Minneapolis, MN	X	X	X	—	X
Anacast Fort Worth, TX	X	X	—	—	X
Teledyne Casting Pomona, CA	X	X	—	—	X
Wallace R. Turner Corp. Cudahy, CA	X	X	—	—	X
Ross Aluminum Sidney, OH	X	—	—	—	X
Morris Bean Yellow Springs, OH	X	X	X	X	X

GENERAL INFORMATION

HOURLY EMPLOYEES

NUMBER	INVESTMENT FOUNDRIES	SAND COMPOSITE FOUNDRIES
Under 100	2	2
100 - 199	2	2
200 - 299	2	1
300 - 399	1	2
400 - 499	-	3
500 - 599	-	1

RATIO OF HOURLY VS QC VS DEGREED EMPLOYEES:

NUMBER	Q.C. - DEGREED	Q.C. - DEGREED
Under 100	7 - 1	4.5 - 1.5
100 - 199	16.6 - 1.3	16.5 - 2.5
200 - 299	33 - 9	50 - 5
300 - 399	30 - 0	21.5 - 0.5
400 - 499		40.3 - 5.7
500 - 599		60 - 6

PERCENTAGE OF MIL-A-21180 CASTINGS:

NUMBER	INVESTMENT FOUNDRIES	SAND COMPOSITE FOUNDRIES
Under 100	70	70
100 - 199	18	25
200 - 299	52.5	90
300 - 399		32.5
400 - 499	-	37
500 - 599	-	65

IN-HOUSE FOUNDRY CONTROL:

TEST	PROCESS			
	SAND COMPOSITE		INVESTMENT	
	YES	NO	YES	NO
MELTING				
Spectrographic	11	0	6	0
Vacuum Test	10	1	4	2
Temperature	10	1	6	0
Fracture	2	9	2	5
Chill Plate	2	9	0	0
Grain Size	3	8	1	5
POURING TEMPT	11	0	6	0
SOLIDIFICATION				
As-Cast X-ray	11	0	6	0
As-Cast Penetrant	11	0	5	1
Ultrasonic	0	11	0	6
HEAT TREATMENT				
Hardness	9	2	6	0
Conductivity*	1	2	3	1
Sep. Cast T/B	7	4	4	2
Attached T/B	11	0	3**	3
Gated T/B	2	9	3	3
Excised T/B	10	1	4**	2

NOTES: * for 201 only
** may be prolongation

EQUIPMENT USED FOR FOUNDRY METALLURGICAL CONTROL AND PURPOSE

TESTING EQUIPMENT	PURPOSE	USED BY S/C	USED BY INVEST
Spectrograph	Melt Chemistry	11	6
Gas Detector	Melt Gas Content	10	4
Pyrometer	Melt Temperature	11	6
X-ray	As-Cast Quality	11	6
Penetrant	As-Cast Quality	11	6
Tensile	H.T. Properties	9	5
Hardness	H.T. Properties	10	6
Conductivity	Heat Treatment	2	2
Ultrasonic	Soundness	0	0
Metallographic	Resolve Problems (grain size, DAS, etc.)	9	2
Photographic	Document Molding	11	6

PROCESSES DOCUMENTED FOR CONTROL

	INVEST		S/C	
	P/N	G	P/N	G
Melting	1	5	5	11
Chemistry	3	4	8	7
Molding Materials & Assembly	6	0	10	1
Rigging	6	0	10	1
Chilling	5	0	11	0
Pouring Temperature	6	0	11	1
Solution Treatment (T&T)	3	5	9	4
Quenchant (Type & Tempt)	3	5	9	2
Aging Treatment (T&T)	4	5	10	3
Weld Repair	5	3	7	6

NOTES: S/C = Sand Composite
P/N = Part Number
G = General
T&T = Temperature & Time

FINAL INSPECTION AND TESTING (RECOMMENDED)

TEST	PROCESS: SAND COMPOSITE Each Casting	Each Melt H.T. Lot	Reduced Sampling	INVESTMENT Each Casting	Each Melt H.T. Lot	Reduced Sampling	Other
Chemistry		9	1		4		
X-ray	11			5		1	
Penetrant	11			6			
DAS	3		2[(a)]				
ICTB or Prolongation	6	3	2[(b)]	4	2[(b)]		
SCTB		4					
Excise T/B	2[(c)]	4	5	1[(c)]		1	2[(d)]
Hardness	6	3	1	6			
Conductivity	1[(e)]			3[(e)]			

NOTES:
(a) MRB only
(b) Each HT Lot
(c) By count
(d) F.A. only
(e) 201 only

SCTB - Separately Cast Test Bar
ICTB - Integrally Cast Test Bar
DAS - Dendrite Arm Spacing

FIRST ARTICLE FOUNDRY CONTROL APPROVAL PROCEDURE

		Invest	S/C
Necessary	Yes	6	11
	No	0	0

Should be Performed by:

	Invest D	Invest Q	S/C D	S/C Q
Foundry and User Independently	3	3	3	3
Combined	3	4	8	5
Approved Lab				3

NOTES: D — Dimensional
Q — Quality

Requirements Should be More Stringent for F/A

	Invest	S/C
Yes		1
No	5	7

ARE USER SURVEYS OF FOUNDRIES DONE ADEQUATELY TO IDENTIFY THOSE FOUNDRIES CAPABLE OF MAKING MIL-A-21180 CASTINGS?

	Inv.	S/C
Yes	3	4
No	2	6

WHAT IDENTIFIES A FOUNDRY THAT IS CAPABLE OF PRODUCING MIL-A21180 CASTINGS?

A. Technical Capability - as measured by:

Investment Foundries

- Performance record
- Test results of production castings
- Experience between user and foundry
- Quality of customers
- Traceability of records
- Check results with customers
- Ratio of QC personnel to production
- Ratio of degreed personnel to production
- Spot audits by user
- Compliance to QC manual

Sand Composite Foundries

- Observe foundry control tests and equipment
- Active technical staff
- In-house testing equipment
- Control documentation
- Ratio of degreed engineers
- Test results
- Intuition
- Housekeeping
- Attention to details
- Pride of workmanship
- Experience
- Reputation

Sand Composite Foundries (Continued)

- Knowledge of DAS
- Customer list
- Traceability of records

B. Management Interest -

Investment Foundries

- Personal judgement
- Performance records
- QC and engineering personnel
- RFQ exceptions
- Good housekeeping
- Price quoted
- Solicitation of bids
- Foundry records
- Customer records

Sand Composite Foundries

- Shows interest in RFQ
- Past experience
- Present product mix
- Record of performance
- Customer list

PROCUREMENT PROCEDURES

	Yes		No	
	S/C	Inv.	S/C	Inv.
a. Does transferred equipment produce acceptable parts?	3	4	7	2
b. Does delivery pressure reduce the quality development effort?	4	2	6	4
c. Are customers approved sources capable?	8	4	1	1
d. Does annual re-bid requirement reduce interest?	-	1	10	5

PROCUREMENT PROCEDURES (Continued)

		Yes		No	
		S/C	Inv.	S/C	Inv.
e.	Do ambiguous requirement call-outs necessitate price-padding or gambling?	5	1	5	5
f.	Is customer slow to provide clarification?	4	2	6	'4
g.	Usually a slow feedback from customer?	3	2	7	4
h.	Do customer representatives understand foundrywork?	3	4	7	2
i.	Are specifications more complicated than necessary?	1	2	8	3
j.	Too many specifications	2	3	-	-
	Too few specifications	1	0	-	-
	Number O.K.	5	2	4	1
k.	Do RFQ and P.O. contain all the necessary information?	5	5	4	1
l.	Is a casting drawing supplied?	8	5	1	-
m.	Is a machined part drawing supplied?	2	-	6	-
n.	Is a machined part drawing wanted?	4	4	1	1

PROCESS VARIABLES REQUIRING MORE EVALUATION

A. Investment Foundries

- None
- Microshrinkage effect on tensile properties
- Strontium modification procedure
- (Better user analysis of requirements to prevent over-design)

B. Sand-Composite Foundries

- Silicon modification procedure using sodium and strontium
- Effect of phosphorous on silicon modification
- Properties vs grain size and DAS
- Thermal gradient vs gas content vs tensile properties
- Tensile properties vs thickness

B. Sand-Composite Foundries (Continued)

- Quench rate vs thickness
- Realistic range for iron and magnesium contents
- SCC of C355
- Effect of DAS
- Development of higher strength alloys

WHAT SHOULD BE CHANGED IN MIL-A-21180?

A. Remove from specification

Investment Foundries

No. of Replies	Item
2	Higher X-ray quality of first article
2	Heat treat requirements — recommend only
2	Temperature of quenchant (MIL-H-6088)
1	Destructive testing for large parts
1	Destructive testing for all parts
1	Nothing (to keep out inferior foundries)
1	Reference to MIL-C-6021 and information to specification
1	Tensile property requirement for designated areas
1	Raised serial numbers requirement

Sand Composite Foundries

No. of Replies	Item
7	Higher X-ray quality of first article
1	Maximum on Beryllium content
2	Minimum on Titanium content
3	Heat treat requirements — recommend only
4	Quench temperature
1	Grade "A" X-ray requirement
3	Minimum on Beryllium content
2	Maximum on Magnesium content in A356

B. Add to Specification

Investment Foundries

No. of Replies	Item
1	Better radiographic standards
1	Sampling plans
1	Correlation of tensile properties with X-ray requirement
1	Requirement to show high stress areas on drawing
1	Minimum change in thickness which requires additional test
1	Test bar size applicable to investment process (minimum thickness)
1	Test requirement for prolongations
1	Requirement for yield strength range of 2 ksi for all areas of the casting

Sand Composite Foundries

No. of Replies	Item
4	Requirement for integral attached coupons
3	Sampling frequency for destructive testing small lots
1	Property levels by process
1	Round gas porosity radiographic quality should be allowed one plate higher in A357
1	Greater taper allowance in tensile specimens
1	Retest provisions which allow witnessing by foundry
1	Sampling plans now in MIL-C-6021
1	Thin tensile specimen dimensions which allow more width
1	Tensile specimen locations
1	Provisions for lower tensile properties in riser areas
1	Range of A356 magnesium content should be 0.25-0.45%
2	Provisions for weld repair
3	Correlation of property level to radiographic quality

DESIGN PRODUCIBILITY LIMITS

Investment Process (all alloys)

Minimum Thickness (inch)	Maximum Thickness (inch)
0.060 (3)	0.375 (2)
0.070 (1)	0.250 (1)
0.080 (2)	0.750 (1)
	1.500 (1)
	2.000 (1)

( ) Number of foundries responding

Sand Composite Process

Alloy	Minimum Thickness (inch)	Maximum Thickness (inch)
A356	0.06 (1)	0.75 (2)
	0.10 (3)	1.00 (1)
A357	0.12 (1)	2.50 (1)
	0.12 (1)	3.00 (3)
	0.18 (1)	5.00 (2)
	0.25 (1)	
A201	0.14 (3)	3.00 (3)
	0.15 (1)	5.00 (1)

( ) Number of foundries responding

APPENDIX B

CASTING USER SURVEY (SUMMARY)

USER SURVEY PURPOSE: to determine the utlization base of aluminum castings procured to MIL-A-21180 type specification requirements for military airframe applications.

USER SURVEY SUMMARY OUTLINE

I. COMPANIES SURVEYED AND TYPES OF PERSONNEL INTERVIEWED

II. RELATIONSHIP OF MINIMUM TENSILE PROPERTY REQUIREMENTS AND CASTING ALLOY AND FOUNDRY PROCESS

III. DESIGN/STRESS CONSIDERATIONS

IV. DESIGN PRODUCIBILITY PROCEDURES

V. QUALITY ASSURANCE REQUIREMENTS

VI. FOUNDRY QUALIFICATION

VII. PROCUREMENT SPECIFICATION REQUIREMENTS

I. Companies surveyed and types of personnel interviewed

A. Military airframe manufacturers surveyed were:

1. Boeing Military Airplane Co.
   Wichita, KS

2. Fairchild Republic Corp.
   Farmingdale, NY

3. General Dynamics
   Fort Worth, TX

4. Grumman Aerospace Corp.
   Bethpage, NY

5. Lockheed-Georgia
   Marietta, GA

6. Lockheed-California Co.
   Burbank, CA

7. LTV Aerospace Corp.
   Dallas, TX

8. McDonnell Douglas
   St. Louis, MO

9. McDonnell Douglas
   Long Beach, CA

10. Northrop Corp.
    Hawthorne, CA

Other companies surveyed because of their high usage of MIL-A-21180 castings were:

1. The Boeing Company
   Seattle, WA
   - ALCM Program
   - Cast Program
2. Bell Helicopter
   Fort Worth, TX
3. Hughes Helicopter
   Culver City, CA

B. Personnel interviewed represented the following departments:

Materials and Process
Structural Analysis
Design
Quality Control
Producibility
Procurement

C. Survey Time Period

Survey was conducted within a time frame of April-July 1980.

III. DESIGN/STRESS CONSIDERATIONS	NO. OF AFFIRMATIVE RESPONSES
A. Casting Property Minimums Are Specified	13
B. Castings Are:	
1. Critical to Flight Safety or Release of Stores or Abortion of Mission	9
2. Have Redundant Load Paths	5
3. Classified in Accordance with MIL-C-6021	13

X-Ray Grades Designated	9
Property Level Designated	8

C. Component Structural Test Is Used to Qualify Each Design

Class 1 Only	5
Classes 1, 2, and 3	4

D. Casting Factor is Used in the Stress Analysis 9

E. What Casting Factor Is Used in the Stress Analysis?

1.00	3	1.25	2	1.33	7
1.50	3	2.00	1	3.00	1

F. Where Does the Requirement for a Casting Factor Originate?

MIL-008860A	6
AFSC DH 1-2	4
Company Policy	4
In Lieu of Structural Test	1

G. What Is Required to Eliminate Use of Casting Factor?

1. Delete requirement in MIL-008860A and AFSC DH 1-2 3
2. Develop QA procedure for higher reliability 6
3. Develop statistical basis for allowables 1
4. Develop more test data to show consistency 3
5. Explain evolution of process which provides higher and more reliable properties 1

H. Additional Information Needed for Primary Structure/Usage

1. Publish flight test history 1
2. Increase minimum property level to equal wrought alloys 2
3. Develop damage tolerance and fracture toughness information 8

IV. DESIGN PRODUCIBILITY PROCEDURES

A. Is Producibility Criteria Defined in Company Design Manual?

1.	General (all quality)	12
2.	Specific (premium quality)	0

B. Who Review Drawing to Determine Producibility?

1.	User Team	4
2.	Foundry (red-line) only	3
3.	Producibility Engineer only	4
4.	M&P Engineer only	3

C. Do Drawings Specify Method of Production?

(Investment — Sand — P/M)

Yes	9
No	3

V. QUALITY ASSURANCE REQUIREMENTS

A. How Are Production Castings Selected for Destruct Testing?

1.	At Random	5
2.	Least Acceptable X-Ray	3
3.	Not Required	4

B. What Frequency of Destruct Testing is Used?

1.	MIL-STD-105 (Each Melt/H.T. Lot)	2
2.	By Count	5
3.	Preproduction Only	4
4.	Each Heat Treat Lot	1

C.	Specify Location Excised Test Bars Are to be Taken	7
D.	Tensile Specimens Are Retested if Failure Occurs Through a Flaw That is Radiographically Acceptable?	11
E.	Tensile Tests Procedures Are in Accordance with ASTM E8?	11
F.	Restrict the Use of Process Welding	11

G. Identification Required for Traceability:

On the Casting

	Vibro Etched or Ink Stamped	Cast-on
Serial No.	3	1
Melt No.	4	
H.T. Lot	5	
X-Ray No.	8	

H. Tests Used That Are Not Required by MIL-A-21180:

1.	Integral Test Bar	9
2.	DAS	1
3.	Hardness 100%	1
4.	Special Technique for Measuring % Elongation	1
5.	Separately Cast T/B	4
6.	Integrally Gated Test Bar	1

I. Who Pays the Testing Facility?

	User	Foundry
1. NDT	5	7
2. Tensile	5	9

J. Who Tests First Article?

	NDT	Tensile	DIMS
1. Foundry (at approved lab)	9	5	10
2. User	4	6	6
3. Combined	3	2	7
4. Independently	3	4	3

K. Who Does Production Testing?

	Approved Source	User	Both
1. Chemistry	11	1	1
2. Penetrant	9	2	1
3. X-Ray	12	0	5*
4. Hardness	3	7	2
5. Tensile - INT T/B	5	1	1
- SEP T/B	3	-	-
- EXC T/B	5	4	-
6. Dimensional	6	2	4

*Note: Review only

L. Record Is Maintained of Foundry Performance 12

VI. FOUNDRY QUALIFICATION PROCEDURE	RESPONSES
A. A Qualified Source List Is Used	5
B. MIL-A-21180 Sources Are Identified	1
C. Who Determines Qualified Source for MIL-A-21180 Castings?	
1. Team Survey Only	1
2. QC Only	11
3. Purchasing Only	1
4. Engineering Only	0
D. What Determines Source Capability?	
1. Special Equipment	7
2. Technical Personnel	7
3. Performance History	10
4. QC Documentation	7
5. Management Interest	3
E. When Is Source Requalification Necessary?	
Change of:	
1. Technical Personnel	4
2. Management	4
3. Quality Performance	5
VII. SPECIFICATION REQUIREMENTS	
A. MIL-A-21180 or a Similar Company Specification Used for Casting Procurement?	13
B. What Modifications Are Needed to MIL-A-21180?	
1. Add provisions for a qualified source list	2
2. Remove MIL-STD-105	8
3. Eliminate requirement for higher X-Ray grade of pre-production part	10
4. Add provision for allowing process welding	5
5. Add requirement for cast-on serial number	2

6.	Change "required" H.T. procedure to "recommended" H.T. procedure	2
7.	Increase tensile property requirements for preproduction casting	1
8.	Equate testing requirements with margin of safety	1
9.	Remove "Options"	2
10.	Add requirement for integral attached coupon or prolongation	6
11.	Relate minimum properties to molding process	3
12.	Define conditions which allow retesting	3
13.	Provide for testing of casting too small to excise tensile specimen	2
14.	Establish QA test requirement for each process variable	2
15.	Eliminate 5% elongation requirement	1
16.	Remove requirement to negotiate properties with foundry	1
17.	Relate to margin of safety	1
18.	Reduce testing with confidence	1
19.	Remove alloy and property requirements (use drawing notes)	1
20.	Improve tensile test procedure (defects have greater effect on smaller specimens; therefore, property minimum should be lower)	1
21.	Relate X-ray quality and tensile properties	2
22.	Define surface quality	1
23.	Establish schedule for preproduction qualification	1
24.	Delete alloys C355, 354, A357	2
25.	Delete grade "A" X-ray requirement	3

APPENDIX C

AN EVALUATION OF RADIOGRAPHIC PROCESS FOR DETERMINING GRADE C QUALITY MATERIAL

AN EVALUATION OF RADIOGRAPHIC PROCESSES FOR DETERMINING GRADE C QUALITY MATERIAL

Background

The purpose of this task was to determine the transition thickness of the casting for a grade "C" defect. The transition thickness is defined as that thickness in which a known grade of defect appears to be acceptable at the next higher grade. In this instance, the transition thickness occurs when the "C" defect appears to be acceptable as grade "B" radiographic quality. Casting plates 0.12 inch and 0.14 inch thick with grade "C" dross, gas porosity and sponge shrinkage respectively were collected from several foundries. The thin plate with the defects was sandwiched in between wrought aluminum plates of various thickness and x-rayed. Various x-ray techniques were evaluated to maximize the transition thickness. Three independent x-ray laboratories were consulted to read the films so that the variation of defect level due to human factors could be minimized or eliminated.

General Procedure:

I.

a. Place flawed material (with gas) in the center of the stack.

b. Sandwich the flawed plate with 0.050 inch thick 6061 aluminum plates (thickness of stack 0.220 inch) and x-ray.

c. Sandwich the flawed plate with 0.50 inch thick, 6061 aluminum plates (thickness of stack 0.320 inch) and x-ray.

d. Sandwich b. with 0.150 inch (thickness of stack 0.520 inch) and x-ray.

e. Sandwich b. with 0.050 inch, 6061 aluminum plates (thickness of stack 0.620 inch) and x-ray.

II. Determine when the radiographic image changes from grade "C" to grade "B". If the image appears to be grade "B", then go back to process d, or process c.

III. Compare the above x-ray reading with:

a. Flawed plate on top of stack.
b. Flawed plate on bottom of stack.

IV. Repeat the above with flawed material of shrinkage and dross, respectively.

Radiographic Techniques:

	Standard Process (A)	(A) + Beryllium Window	(A) + Long Exposure Time
Exposure Time (Seconds)	45	60	180
Milliamperes	7.5	15	3.5
Kilovolts	50-80	50-100	50-60
Focal Film Distance (Inch)	36	45	45
Focal Spot Size (inch)	0.059	0.098	0.059
Ug (Unsharpness Inch)	0.0016	0.0021	0.0016

Results:

The standard "C" quality grade defect was interpreted as a "B" quality grade defect when the stack thickness was increased. The results were as follows for each radiographic technique.

Standard Technique:

		Radiographic Quality		
Stack Thickness (Inches)	K.V.	Gas Porosity	Sponge Shrinkage	Dross. Less Dense
0.220	50	C	C	C
0.300	55	C	C	C
0.380	60	C	B	C
0.460	65	B	B	B
0.540	70	B	B	B
0.610	75	B	B	B
0.900	80	B	B	B

Standard Technique Plus Beryllium Window:

Stack Thickness (Inches)	K.V.	Radiographic Quality: Gas Porosity	Sponge Shrinkage	Dross, Less Dense
0.200	50	C	C	C
0.340	55	C	C	C
0.440	60	C	C	C
0.540	75	C	C	C
0.640	80	C	C	B
0.740	85	B	C	A
0.830	95	B	B	A
0.930	100	B	B	A

Standard Technique Plus Long Exposure:

Stack Thickness (Inches)	K.V.	Radiographic Quality: Gas Porosity	Sponge Shrinkage	Dross, Less Dense
0.200	50	C	C	C
0.340	52	C	C	C
0.400	54	C	C	C
0.540	56	C	C	C
0.640	58	B	C	B
0.640T*	58	B	B	B
0.640B**	58	B	B/C	B
0.700	60	B	A	A

*Defect plate on top of stack.

**Defect plate at bottom of stack

SUMMARY AND CONCLUSIONS:

1. The acceptable thicknesses range for the three types of defects evaluated, varied by technique in the following manner:

STD Technique	0.300 - 0.360 Inch
STD + Beryllium Window	0.540 - 0.740 Inch
STD + Long Exposure	0.540 - 0.540 Inch

2. The maximum thickness of material for which all types of Grade C defects could be detected was 0.540 inches thick.

3. The special processes were considered to be equal to each other but better than the standard radiographic process in their capability to determine grade "C" quality defects.

APPENDIX D

STATISTICAL ANALYSES OF
MECHANICAL PROPRETY DATA

STATISTICAL ANALYSES OF MECHANICAL PROPERTY DATA FROM NORTHROP CORPORATION/AIR FORCE CASTING RESEARCH PROGRAM

March 1, 1984

by

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STATISTICAL ANALYSES OF MECHANICAL PROPERTY DATA FROM NORTHROP CORPORATION/AIR FORCE CASTING RESEARCH PROGRAM

Introduction and Data Description

Mechanical property data from the Northrop Corporation/Air Force casting research program (reference 5) was submitted to Battelle's Columbus Laboratories for statistical analyses utilizing funds from the MIL-HDBK-5 program. Mechanical property data for A357-T6 castings from Suppliers A and B were received in reference (1) and (4) while data for A201-T-7castings from Suppliers C and D were transmitted via references (2) and (3), respectively. The castings were produced to Northrop specifications. The test specimens were from a standard step plate with specimens taken from "designated" and "nondesignated" areas of the plate. On the drawing of a cast part, the "designated" area shows the area having maximum stresses while the "non-designated" area has lower stresses. Obviously, the highest mechanical properties are required in the "designated" area.

Approximately 50 tensile property observations were available from the "designated" area and 30 observations from the "nondesignated" area for each supplier. The tensile properties were obtained from step plates representing five melts with castings heat treated in two heat treat lots constituting 10 lots of castings for each supplier. Compression, shear, and bearing data were also available for five lots of castings from each supplier. One compression, shear, bearing (e/D = 1.5), and bearing (e/D = 2.0) test specimen was taken from each of five lots of castings for each supplier.

Summary

Statistical based MIL-HDBK-5 design mechanical property values were determined for A357-T6 cast test plates. The data from the two suppliers were representative of cast test plates produced to stringent Northrop specifications. An equivalent public specification is not yet available. Such a specification has not been accepted by casting suppliers and the producibility of cast parts to such a specification has not been investigated. It is not known whether the statistical based A and B values for tensile yield with ultimate strength will be representative of cast parts. Consequently, it is recommended that a program be undertaken to demonstrate this applicability as soon as cast parts are available to this new specification. It is

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(1) Northorp letter, Oswalt to Ruff, dated August 18, 1983 (MIL-HDBK-5 Source M-585).

(2) Northorp letter, Oswalt to Ruff, dated August 4, 1983 (MIL-HDBK-5 Source M-599).

(3) Northrop letter, Oswalt to Ruff, dated August 30, 1983 (MIL-HDBK-5 Source M-601).

(4) Northrop letter, Oswalt to Ruff, dated January 18, 1984 (MIL-HDBK-5 Source M-605).

(5) "Manufacturing Methods for Process Effects on Aluminum Casting Allowables", Northrop Corporation, Air Force Contract F33615-79-5116.

believed that it will not be necessary to validate the reduced (lower tolerance limit) ratios used to compute the compression, shear, and bearing design values since it is unlikely that these ratios would vary significantly from the test plate to the part.

The A201-T7 mechanical property data representative of cast test plates from two suppliers were analyzed to determine MIL-HDBK-5 design values. The test plates were produced to stringent Northrop specifications. The tensile yield and ultimate strength populations for the two suppliers were different and could not be combined. The distributions of tensile yield and ultimate strengths in the "designated" area were non-normal for one supplier and A values could not be determined nonparametrically due to the small sample size. This supplier produced the lower strength material. According to MIL-HDBK-5 guidelines A and B values are based upon the supplier producing the lowest strength material when data from various suppliers cannot be combined. Consequently, A and B values for A201-T7 could not be determined due to the small quantity of data. Reduced (lower tolerance limit) ratios, which can be used to compute compression, shear, and bearing design values after the design values for tensile yield and ultimate strength have been established, were determined. The comments regarding the applicability of A357-T6 tensile property data to cast test parts are equally appropriate for A201-T7.

Analyses of A357-T6 Data

The A357-T6 tensile data from Suppliers A and B were analyzed to determine A and B values* in accordance with MIL-HDBK-5 guidelines (Chapter 9). The following equations were used to compute these values:

$$A = \bar{X} - k_A s,$$
$$B = \bar{X} - k_B s,$$

where $\bar{X}$ = sample mean based on n observations

s = standard deviation

k_A = one-sided tolerance-limit factor corresponding to a proportion at least 0.99 of a normal distribution and a confidence coefficient of 0.95

k_B = one-sided tolerance-limit factor corresponding to a proportion at least 0.90 of a normal distribution and a confidence coefficient of 0.95.

Summaries of the statistics are shown in Tables 1 through 4. The distributions were normal for both tensile yield and ultimate strengths for both the "designated"

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*A-value. The mechanical-property value above which at least 99 percent of the population of values is expected to fall, with a confidence of 95 percent.

B-value. The mechanical-property value above which at least 90 percent of the population of values is expected to fall, with a confidence of 95 percent.

and "nondesignated" areas for both Suppliers A and B with the exception of the tensile ultimate strength for the "nondesignated" area for Supplier B. This non-normal distribution was negatively skewed as shown in Figure 1. An A value for this non-normal distribution could not be determined non-parametrically because of the small quantity of data. The A and B values for the "designated" and "nondesignated" areas for Supplier A were nearly identical.

The variances were very low possibly due to the fact the data were from a standard test block (one configuration and thickness). For Supplier B the yield and ultimate tensile strengths of the "nondesignated" area were slightly lower than those of the "designated" area. Since the values for mean and standard deviation appeared similar for the two suppliers, the "F" and "t" tests were conducted in accordance with MIL-HDBK-5 guidelines to determine if the data from the two suppliers constituted a single population. The "F" test is used to first determine whether the two sample variances differ (or do not differ) significantly, after which the "t" test is used to evaluate whether the two sample means differ significantly. The results of the tests are shown in Tables 5 and 6. For the "designated" area the variances of Suppliers A and B did not differ significantly; however, the averages differed significantly. Consequently, the data from the two suppliers constituted different populations and should not be combined. For the "nondesignated" areas, the variances for tensile ultimate strength as well as the averages were significantly different. A comparison of A and B values with S values from MIL-A-21180 is shown in Table 7.

According to MIL-HDBK-5 guidelines, a minimum of 100 observations are required for the determination of A and B values for incorporation in MIL-HDBK-5. If the A and B values for material (from Supplier B) having the lower strength were utilized for MIL-HDBK-5 A and B values, the quantity (50 observations) of data would not comply with the MIL-HDBK-5 guidelines.

Although the "F" and "t" tests indicated that the tensile yield and ultimate strength averages for the "designated" area were not equivalent, the magnitude of the differences were small (3 percent or less); consequently, the data from Suppliers A and B were combined and reanalyzed with the results shown in Table 8. The variances increased compared to variances in Tables 1 and 3 and the distributions were normal. The A and B values were very similar to the A and B values for each supplier.

The A-values from the two suppliers as well as the A values from the combined data from the two suppliers support a specification value of 50 ksi for tensile ultimate strength and 40 ksi for tensile yield strength. If a new specification is established using these specification minimum values, the S basis value would be used in lieu of the tensile yield strength A value in the MIL-HDBK-5 design allowable table because the A value is higher than the S value. The A value and S value for tensile ultimate strength would be the same. The B values from Table 7 could be used in the design allowable table. The A and B values for tensile yield and ultimate strength in the "designated" area are presented in Table 22. It is recommended that A and B values not be established for the "nondesignated" area because these properties are concomitant to the properties in the "designated" area. The

cooling rate of material in the "nondesignated" area may be slower (due to the absence of chill bars) and the radiographic quality requirements as specified on the drawing may be lower than for the "designated" area. Although the properties in the "nondesignated" area were not significantly different than those for the "designated" area in this investigation, it is recommended that specification minimum values for tensile yield and ultimate strength be established arbitrarily at 10 percent below the specification values for the "designated" area. Hence, the specification values for the "nondesignated" areas are 45 ksi for tensile ultimate strength and 36 ksi for tensile yield strength as shown in Table 22. The elongation data exhibited a non-normal distribution and A values could not be determined nonparametrically because of insufficient data. Elongation values are presented on an S-basis only in MIL-HDBK-5. It is recommended that specification minimum elongation value be 3 percent for the "designated" area based upon the B value and 2 percent for the "nondesignated" area based upon an arbitrary 33 percent lower value due to less stringent radiographic requirements for the "nondesignated" area.

Design values for compression, shear, and bearing strengths are normally derived because the quantity of data is usually insufficient to determine these allowables in the same manner as for tensile yield and ultimate tensile strengths. These mechanical property values are established through their relationship to the directly calculated values (A, B, or S) for tensile ultimate strength (F_{tu}) and tensile yield strength (F_{ty}) The procedure involves the pairing of individual (or lot average) shear ultimate strength (SUS) and bearing ultimate strength (BUS) measurements with corresponding tensile ultimate strength (TUS) for which F_{tu} has been established to form ratios. Likewise, individual compressive yield strength (CYS) and bearing yield strength (BYS) measurements are mated with tensile yield strength (TYS) measurements for which F_{ty} has been established to form ratios.

The design values for compressive yield strength (F_{cy}), bearing yield strength (F_{bry}), shear ultimate strength (F_{su}), and bearing ultimate strength (F_{bru}) were determined using the computational procedure in the MIL-HDBK-5 guidelines (Chapter 9). The following equation was used to compute reduced ratios:

$$R = \bar{r} - \frac{t_{0.95}s}{\sqrt{n}}$$

where R = reduced ratio

$\bar{r}$ = average of n ratios

s = standard deviation of the ratios

$t_{0.95}$ = the 0.95 fractile of the t distribution corresponding to n-1 degrees of freedom

n = number of ratios

For the A357-T6 castings, one compression, shear, and bearing test was conducted on each lot; therefore, individual compression, shear, and bearing values were mated to the individual companion tensile value - not the tensile value representing the lot average. Since the tensile strength observations varied considerably for some lots, this procedure provided more accurate ratios. Compression, shear, and bearing data were analyzed separately for "designated" and "nondesignated" areas of the casting. Only five ratios were available for each of the two areas. The results of these analyses are presented in Tables 9 through 16. A comparison of the average ratios for the "designated" and "nondesignated" areas is shown in Table 17. For Supplier B the average ratios for the "nondesignated" area were higher than for the "designated" area. This fact is somewhat difficult to explain. The difference may not be significant and may be due to the small sample size (five ratios). The ratios for the "designated" and "nondesignated" areas exhibited reasonable good agreement. Since there is considerable risk involved in attempting to determine whether two populations or data sets are significantly different for small quantities of data, the data for the "designated" and "nondesignated" areas for each supplier were combined and reanalyzed. A summary of the resulting reduced ratios is presented in Table 18. Since most of the mechanical property ratios for the two suppliers exhibited reasonably good agreement, the data for the two suppliers were combined and reanalyzed with the results shown in Tables 19 and 20. The reduced ratios used to compute the compression, shear, and bearing design values for A357-T61 castings in MIL-HDBK-5 Table 3.9.6.0(b) were determined via Item 65-5 and approved at the 30th Meeting. The Boeing Company also determined reduced ratios for A357-T6 in the CAST program, reference (6). A comparison of the reduced ratios determined from the data from Suppliers A and B with those used to compute existing design allowables and those from the CAST program are shown in Table 21. The reduced ratios for castings from Suppliers A and B and those from the CAST program exhibited fairly good agreement except for $\frac{SUS}{TUS}$ which was 14 percent higher. The difference in the $\frac{SUS}{TUS}$ reduced ratios may have been caused by the use of different types of shear tools since there are no standards for shear testing. The other mechanical property ratios when compared to the Boeing reduced ratios exhibited less than 6 percent difference. The reduced ratios for A357-T61 castings used to compute the existing design values in MIL-HDBK-5 were based upon limited data and, therefore, are conservative, except for SUS/TUS and $\frac{BYS}{TYS}$, e/D = 1.5, which are unconservative based upon the Northrop data. As a result of this comparison, the reduced ratios determined from the data from Suppliers A and B appear reasonable and have been used to compute the compression, shear, and bearing design values in Table 22.

When an AMS or government material specification, which is equivalent to the Northrop specification used to procure the castings tested in this program, is published, the design allowables presented in Table 22 can be considered for inclusion in MIL-HDBK-5. The design values in Table 22 are based

(6) McLellan, D.L., "Cast Aluminum Structures Technology (CAST) Structural Test and Evaluation (Phase V) Part III - Static Property Allowables", AFWAL-TR-80-3021, April 1980.

upon data from test plates. A stringent material specification representative of the specification used to procure these test plates has not been accepted by the casting suppliers and actual parts have not been produced to such a specification. The producibility of cast parts to such a specification has not been investigated. It is not known whether the A and B values for tensile yield and ultimate strengths shown in Table 22 will be representative of cast parts; consequently, it is recommended that a program be undertaken to demonstrate this applicability as soon as cast parts are available to this new specification. It is believed that the reduced ratios for compression yield strength, shear ultimate strength, and bearing yield and ultimate strengths would not vary greatly from test plate to cast part; consequently, there is no need to determine the validity of the reduced ratios for cast parts. The design values for A357-T6 in Table 22 represent the capability of a specific process and procurement specification and perhaps could be incorporated into MIL-HDBK-5 with an appropriate footnote of caution.

Analyses of A201-T7 Data

The A201-T7 tensile data from Supplier C and Supplier D were analyzed to determine A and B values in accordance with MIL-HDBK-5 guidelines. Summaries of the statistics are shown in Tables 23 through 26. As indicated in Table 23, the distributions of the Supplier C data from the "designated" area were non-normal. The distributions tended to be bimodal as shown in Figure 2. Investigation revealed that specimens at the T1 and T3 locations, which were adjacent to risers, exhibited approximately 10 percent lower tensile yield and ultimate strengths compared to specimens at the T2 and T4 locations accounting for the bimodal distributions.

The distributions of the Supplier C data from the "nondesignated" area were normal as shown in Table 24. The mean values for the strengths from the "designated" area were about 3 ksi higher than from the "nondesignated" area for the Supplier C data. Due to the small quantity of data, nonparametric analysis was not applicable for determination of an A value.

For the Supplier D data, the distributions were normal for both the "designated" and "nondesignated" areas, Tables 25 and 26. There did not appear to be any significant difference in the mean and standard deviations for the "designated' and "nondesignated" areas of Supplier D castings.

A visual examination of the values for the mean and standard deviations for Supplier C and Supplier D data revealed sufficient differences in mean and standard deviation values to suggest that the two samples were separate populations. In order to determine definitely whether the samples were from different populations, the "F" and "t" tests were conducted in accordance with the guidelines. The results from performing these tests, as displayed in Tables 27 and 28, indicated conclusively that the data from Supplier C and Supplier D constituted different populations in both the "designated" and "nondesignated" areas and these data should not be combined.

In order to determine the effect of combining a sample having a normal distribution with one having a bimodal distribution, the data were combined and reanalyzed, Table 29. The resulting distributions for both yield and ultimate strengths were negatively skewed as shown in Figure 3. Although negatively skewed, the distribution of the ultimate tensile strength values was normal according to the Chi-square test while the distribuiton of the tensile yield strength values were non-normal. Due to the small sample, nonparametric analysis for determination of A values was not applicable. The two samples should not be combined for the determination of A and B values since they were from different populations.

To summarize, the tensile yield and ultimate strength populations for Suppliers C and D were different and could not be combined. The distributions of the Supplier C tensile strength data from "designated" areas were non-normal and A values could not be determined nonparametrically due to small sample size. The distributions of the Supplier C data from "nondesignated" areas were normal. The mean values were about 3 ksi lower for the "nondesignated" than for the "designated" area. The distributions of the Supplier D tensile strength data were normal for both the "designated" and "nondesignated" areas. There did not appear to be any significant differences in the strengths of the "designated" and "nondesignated" areas. The mean strengths of the Supplier D castings were higher than for Supplier C castings.

The A and B values for A201-T7 castings produced by Supplier C and Supplier D were compared to MIL-A-21180 specification values in Table 30. The specification values from the Northrop specification were unknown. The A values for the Supplier D castings were higher than the MIL-A-21180 S values for both the "designated" and "nondesignated" areas. For Supplier C, the tensile ultimate strength A value was 4 ksi lower than the MIL-A-21180 S value for the "nondesignated" area. Although an A value could not be determined for Supplier C castings for the "designated" area, the nonparametrically determined B value for tensile ultimate strength was equal to the MIL-S-21180 S value; consequently, the A value would be lower than the S value.

The MIL-HDBK-5 guidelines specify that when the data from different suppliers constitute different populations, the A and B values shall be based upon the data from the supplier of the lowest strength material. However, for A201-T7, A values could not be determined from the data for the supplier producing the lowest strength material. If A values could have been determined, these A values would not have been acceptable for inclusion into MIL-HDBK-5 because of the small sample size. The MIL-HDBK-5 guidelines require at least 100 observations for the determination of A and B values. Consequently, additional data are needed to determine A and B values for A201-T7.

Compression, shear, and bearing data were analyzed separately for the "designated" and "nondesignated" areas of casting for each supplier. Individual compression, shear, and bearing values were "paired" to the companion tensile value, not the tensile value representing the lot average because of the considerable variation in tensile strength within a step test

plate for Supplier C. The results of these analyses are presented in Tables 31 through 38. Only five ratios were available for each of the two areas for each supplier. For Supplier C data, the ratios for lot A101 were discarded because the ratios were significantly higher than the other four lots. Investigation revealed that the tensile yield and ultimate strengths of the companion tensile specimen were unusually low causing high ratios. A comparison of the average ratios for the "designated" and "nondesignated" areas is shown in Table 39. For Supplier C the average ratios were higher for the "nondesignated" area than for the "designated" area. This fact is somewhat difficult to explain but may be due to the small sample size (four ratios in some cases). For Supplier D the average ratios for the "designated" area were about the same or higher than those for the "nondesignated" area. There is considerable risk involved in attempting to determine whether two populations or data sets are significantly different for small quantities of data. Consequently, it was decided to combine the data from the "designated" and "nondesignated" areas for each supplier. The reduced ratios from these analyses are presented in Table 40. The reduced ratios from Supplier C data were slightly higher than those from Supplier D data with the exception of $\frac{BUS}{TUS}$ and $\frac{BYS}{TYS}$, e/D - 1.5. The reduced ratios for the two suppliers' data agreed fairly well, except for $\frac{BUS}{TUS}$, e/D = 1.5. Since most of the mechanical property reduced ratios for the two suppliers exhibited reasonably good agreement, it was decided to combine all of the data and reanalyze. The results of these analyses are shown in Tables 41 and 42. A summary of the reduced ratios for A201-T7 castings is shown in Table 43.

Design values for compression, shear, and bearing properties for A201-T7 castings are not available in MIL-HDBK-5. However, these properties are available for A201-T6 castings as established via Item 70-1 and approved at the 39th MIL-HDBK-5 Meeting. The specification tensile properties for the two tempers are identical; therefore, the reduced ratios for the two tempers would be expected to be similar. Consequently, the reduced ratios determined in this analysis for A201-T7 castings are compared to those used to compute compression, shear, and bearing allowables for A201-T6 castings in MIL-HDBK-5 Table 3.8.1.0(b) in Table 43. The reduced ratios for the two tempers exhibited reasonably good agreement. These reduced ratios for A201-T7 castings are considered suitable for use in computing compression, shear, and bearing design values for incorporation in MIL-HDBK-5.

TABLE 1. TENSILE STRENGTH OF A357-T6 CASTING FROM SUPPLIER A, 0.500 INCH THICK DESIGNATED AREA

	TYS, KSI	TUS, KSI	ELONG., %	RED., %
NO. OF DATA	56	56	56	0
AVERAGE	46.34	54.99	.79*	0.00*
STD. DEV.	1.285	1.152	.135*	0.000*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

5	4	8	0
6	5	0	0
6	5	3	0
10	12	0	0
7	4	17	0
1	8	0	0
5	6	13	0
4	2	11	0
5	4	2	0
7	6	2	0

	TYS	TUS	ELONG.	RED.
CHI SQUARED	8.54	12.21	61.55	9999.99
NORMAL	YES	YES	NO	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.	RED.
A BASIS	42.70	51.73	0.00	0.00
B BASIS	44.25	53.12	3.00	0.00

TABLE 2. TENSILE STRENGTH OF A357-T6 CASTING FROM ~~SUPPLIER A,~~ 0.750 ~~INCH THICK~~ NON-DESIGNATED ~~AREA~~

	TYS, KSI	TUS, KSI	ELONG., %	RED., %
NO. OF DATA	38	38	38	0
AVERAGE	45.61	54.39	.82*	0.00*
STD. DEV.	1.171	.831	.116*	0.000*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

4	3	3	0
5	6	2	0
1	1	0	0
7	4	14	0
3	2	0	0
0	6	7	0
6	4	0	0
3	3	4	0
6	5	4	0
3	4	4	0

CHI SQUARED	12.00	6.21	42.53	9999.99
NORMAL	YES	YES	NO	NO

MIL-HDBK-5 A + B VALUES

A BASIS	42.10	51.90	0.00	0.00
B BASIS	43.59	52.95	0.00	0.00

TABLE 3. TENSILE STRENGTH OF A357-T6 CASTING FROM SUPPLIER B, 0.500 INCH THICK DESIGNATED AREA

	TYS, KSI	TUS, KSI	ELONG., %	RED., %
NO. OF DATA	50	50	50	0
AVERAGE	45.29	53.37	.72*	0.00*
STD. DEV.	1.342	.992	.137*	0.000*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

5	5	6	0
2	5	0	0
6	5	11	0
6	3	0	0
6	2	9	0
5	4	0	0
4	6	11	0
4	10	0	0
8	4	5	0
4	5	8	0

CHI SQUARED	4.80	7.20	39.60	9999.99
NORMAL	YES	YES	NO	NO

MIL-HDBK-5 A + B VALUES

A BASIS	41.45	50.53	0.00	0.00
B BASIS	43.08	51.73	3.00	0.00

TABLE 4. TENSILE STRENGTH OF A357-T6 CASTING
FROM SUPPLIER B, 0.750 INCH THICK
NON-DESIGNATEDAREA

	TYS, KSI	TUS, KSI	ELONG., %	RED., %
NO. OF DATA	32	32	32	0
AVERAGE	43.69	50.48	.52*	0.00*
STD. DEV.	1.292	1.794	.141*	0.000*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	5	3	4	0
	2	2	0	0
	2	4	0	0
	1	1	12	0
	2	2	0	0
	4	3	0	0
	6	8	0	0
	3	2	13	0
	6	6	0	0
	1	1	3	0
CHI SQUARED	10.50	14.25	73.62	9999.99
NORMAL	YES	NO	NO	NO

MIL-HDBK-5 A + B VALUES

A BASIS	39.73	0.00	0.00	0.00
B BASIS	41.40	44.80*	1.00	0.00

*Nonparametric determination

TABLE 5. TESTS OF SIGNIFICANCE FOR A357-T6 CASTINGS, DESIGNATED AREA

IDENTIFICATION	TYS, KSI NUMBER	TYS, KSI AVERAGE	TYS, KSI STD.DEV.	TUS, KSI NUMBER	TUS, KSI AVERAGE	TUS, KSI STD.DEV.
A357-T6 CASTING DESIG AREA SUPPLIER A	56	46.34	1.2890	56	54.99	1.1520
A357-T6 CASTING DESIG AREA SUPPLIER B	50	45.29	1.3420	50	53.37	.9920
T = NUMBER OF ITEMS IN GROUP		2.			2.	
DF = NUMBER OF DEGREES OF FREEDOM		104.			104.	
N = HARMONIC MEAN OF N		52.83			52.83	
DX = MAXIMUM DIFFERENCE IN AVERAGES		1.05			1.62	
WV = WEIGHTED VARIANCE		1.7218			1.1655	
WSD = WEIGHTED STANDARD DEVIATION		1.3122			1.0796	
C = BARTLETT #C#		1.0145			1.0145	
CHI SQUARED = 2.3026/C X (X1-X2) =		.0964			1.1316	
TABULAR VALUE FOR ALPHA = .05, T-1 = 1						
THEREFORE CONCLUDE VARIANCES ARE EQUAL		3.84			3.84	
Q(1-ALPHA) = DX/WSD X SQRT(N) = 104		5.8162			10.9070	
TABULAR VALUE FOR ALPHA = .05 T,DF= 2,100						
THEREFORE CONCLUDE AVERAGES ARE NOT EQUAL		2.81			2.81	

TABLE 6. TESTS OF SIGNIFICANCE FOR A357-T6 CASTINGS, NONDESIGNATED AREA

IDENTIFICATION	TYS, KSI NUMBER	TYS, KSI AVERAGE	TYS, KSI STD.DEV.	TUS, KSI NUMBER	TUS, KSI AVERAGE	TUS, KSI STD.DEV.
A356-T6 CASTING NONDESIG AREA SUPPLIER A	38	45.61	1.1710	38	54.39	.8310
A356-T6 CASTING NONDESIG AREA SUPPLIER B	32	43.69	1.2920	32	50.48	1.7960
T = NUMBER OF ITEMS IN GROUP		2.			2.	
DF = NUMBER OF DEGREES OF FREEDOM		68.			68.	
N = HARMONIC MEAN OF N		34.74			34.74	
DX = MAXIMUM DIFFERENCE IN AVERAGES		1.92			3.91	
WV = WEIGHTED VARIANCE		1.5071			1.8430	
WSD = WEIGHTED STANDARD DEVIATION		1.2276			1.3576	
C = BARTLETT #C#		1.0223			1.0223	
CHI SQUARED = 2.3026/C X (X1-X2) =		.3204			18.6225	
TABULAR VALUE FOR ALPHA = .05 T-1 = 1						
THEREFORE CONCLUDE VARIANCES ARE NOT EQUAL FOR TUS		3.84			3.84	
Q(1-ALPHA) = DX/WSD X SQRT(N) =		9.2185			16.9766	
TABULAR VALUE FOR ALPHA = .05 T,DF= 2,68		2.83			2.83	
THEREFORE CONCLUDE AVERAGES ARE NOT EQUAL						

TABLE 7. COMPARISON OF A AND B VALUES WITH S VALUES FROM MIL-A-21180 FOR A357-T6 CASTING

Specification	MIL-A-21180[d]		Northrop							
Thickness, inches	All		0.500							
Supplier	All		Supplier A				Supplier B			
Class	2[a]	11[b]	Designated Area		Non-designated Area		Designated Area		Non-Designated Area	
Basis	S	S	A	B	A	B	A	B	A	B
Mechanical Property:										
F_{tu}	50	41	51	53	52	53	50	51	--	45[c]
F_{ty}	40	31	42	44	42	43	41	43	39	41

[a]Designated area.

[b]Non-designated area.

[c]Determined by nonparametric technique.

[d]T61

TABLE 8. TENSILE STRENGTH OF A357-T6 CASTINGS FROM SUPPLIERS A AND B, 0.500 INCH THICK DESIGNATED AREA

	TYS., KSI	TUS., KSI	ELONG.., %	RED.., %
NO. OF DATA	106	106	106	0
AVERAGE	45.85	54.23	.76*	0.00*
STD. DEV.	1.409	1.349	.140*	0.000*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

8	7	10	0
11	21	15	0
14	11	0	0
7	9	12	0
17	16	0	0
11	12	28	0
7	14	1	0
11	9	17	0
8	7	19	0
12	10	4	0

CHI SQUARED	8.91	7.02	75.13	9999.99
NORMAL	YES	YES	NO	NO

MIL-HDBK-5 A + B VALUES

A BASIS	42.07	50.60	0.00	0.00
B BASIS	43.70	52.17	3.00	0.00

TABLE 9. ULTIMATE STRENGTH RATIOS FOR A357-T6 CASTING
SUPPLIER A, 0.500 INCH DESIGNATED AREA

	KSI	RATIO	e/D = 1.5	e/D = 2.0
	TUS	SUS/TUS	BUS/TUS	BUS/TUS
2237/3-13 MELT 1 H.T. 1 REF(1)	55.3	.613	0.000	2.119
2237/3-14 MELT 1 H.T. 1 REF(1)	54.2	0.000	1.738	0.000
2244/2-17 MELT 2 H.T. 1 REF(1)	54.4	.643	0.000	1.976
2244/2-18 MELT 2 H.T. 1 REF(1)	54.6	0.000	1.753	0.000
2250/4-21 MELT 3 H.T. 1 REF(1)	54.5	.645	0.000	2.238
2250/4-22 MELT 3 H.T. 1 REF(1)	53.6	0.000	1.772	0.000
2256/4-29 MELT 5 H.T. 2 REF(1)	56.2	.616	0.000	2.132
2256/4-30 MELT 5 H.T. 2 REF(1)	54.3	0.000	1.709	0.000
2258/4-34 MELT 4 H.T. 2 REF(1)	54.9	.637	0.000	2.142
2258/4-35 MELT 4 H.T. 2 REF(1)	52.6	0.000	1.745	0.000
	NUMBER R	5	5	5
	AVG R	.631	1.743	2.122
	SUM R	3.154	8.717	10.608
	SUMSQ R	1.990	15.201	22.539
	SDEV R	.0153	.0231	.0939
	SDEV RBAR	.0068	.0103	.0420
	RED. RATIO	.616	1.721	2.032

TABLE 10. ULTIMATE STRENGTH RATIOS FOR A357-T6 CASTING
NON-DESIGNATED AREA SUPPLIER A

	KSI	RATIO	e/D = 1.5	e/D = 2.0
	TUS	SUS/TUS	BUS/TUS	BUS/TUS
F2237/3-13 MELT 1 H.T.1 REF(1)	53.4	.618	0.000	2.122
F2237/3-13 MELT 1 H.T.1 REF(1)	53.6	0.000	1.672	0.000
F2244/2-17 MELT 2 H.T.1 REF(1)	55.0	.615	0.000	2.091
F2244/2-17 MELT 2 H.T.1 REF(1)	52.6	0.000	1.721	0.000
F2250/4-21 MELT 3 H.T.1 REF(1)	56.0	.623	0.000	2.084
F2250/4-21 MELT 3 H.T.1 REF(1)	55.2	0.000	1.717	0.000
F2256/4-29 MELT 5 H.T.2 REF(1)	54.8	.630	0.000	2.186
F2256/4-29 MELT 5 H.T.2 REF(1)	54.1	0.000	1.641	0.000
F2258/4-34 MELT 4 H.T.2 REF(1)	54.4	.642	0.000	2.153
F2258/4-34 MELT 4 H.T.2 REF(1)	54.5	0.000	1.727	0.000
	NUMBER R	5	5	5
	AVG R	.625	1.696	2.127
	SUM R	3.127	8.478	10.635
	SUMSQ R	1.955	14.379	22.629
	SDEV R	.0107	.0373	.0428
	SDEV RBAR	.0048	.0167	.0192
	RED. RATIO	.615	1.660	2.086

TABLE 11. YIELD STRENGTH RATIOS FOR A357-T6 CASTING
SUPPLIER A, 0.500 INCH DESIGNATED AREA

	KSI		RATIO	
			e/D = 1.5	e/D = 2.0
	TYS	CYS/TYS	BYS/TYS	BYS/TYS
2237/3-13 MELT 1 H.T. 1 REF(1)	47.1	1.011	0.000	1.769
2237/3-14 MELT 1 H.T. 1 REF(1)	48.7	0.000	1.548	0.000
2244/2-17 MELT 2 H.T. 1 REF(1)	47.0	1.019	0.000	1.872
2244/2-18 MELT 2 H.T. 1 REF(1)	47.5	0.000	1.598	0.000
2250/4-21 MELT 3 H.T. 1 REF(1)	48.4	1.021	0.000	1.773
2250/4-22 MELT 3 H.T. 1 REF(1)	47.7	0.000	1.589	0.000
2256/4-29 MELT 5 H.T. 2 REF(1)	47.0	1.013	0.000	1.902
2256/4-30 MELT 5 H.T. 2 REF(1)	45.4	0.000	1.634	0.000
2258/4-34 MELT 4 H.T. 2 REF(1)	48.1	1.040	0.000	1.867
2258/4-35 MELT 4 H.T. 2 REF(1)	47.1	0.000	1.586	0.000
NUMBER R		5	5	5
AVG R		1.021	1.591	1.837
SUM R		5.103	7.956	9.183
SUMSQ R		5.208	12.662	16.880
SDEV R		.0114	.0308	.0616
SDEV RBAR		.0051	.0138	.0276
RED. RATIO		1.010	1.562	1.778

TABLE 12. YIELD STRENGTH RATIOS FOR A357-T6 CASTING
NON-DESIGNATED AREA, SUPPLIER A

	KSI		RATIO	
			e/D = 1.5	e/D = 2.0
	TYS	CYS/TYS	BYS/TYS	BYS/TYS
37/3-13 MELT 1 H.T.1 REF(1)	45.5	1.015	0.000	0.000
44/2-17 MELT 2 H.T.1 REF(1)	46.8	1.000	0.000	0.000
50/4-21 MELT 3 H.T.1 REF(1)	46.2	1.039	0.000	0.000
56/4-29 MELT 5 H.T.2 REF(1)	44.5	1.045	0.000	0.000
58/4-34 MELT 4 H.T.2 REF(1)	46.6	1.043	0.000	0.000
37/3-13 MELT 1 H.T.1 REF(1)	45.5	0.000	1.589	0.000
44/2-17 MELT 2 H.T.1 REF(1)	44.6	0.000	1.623	0.000
50/4-21 MELT 3 H.T.1 REF(1)	47.2	0.000	1.604	0.000
56/4-29 MELT 5 H.T.2 REF(1)	45.1	0.000	1.594	0.000
58/4-34 MELT 4 H.T.2 REF(1)	46.1	0.000	1.616	0.000
37/3-13 MELT 1 H.T.1 REF(1)	44.6	0.000	0.000	1.852
44/2-17 MELT 2 H.T.1 REF(1)	45.3	0.000	0.000	1.971
50/4-21 MELT 3 H.T.1 REF(1)	46.8	0.000	0.000	1.861
56/4-29 MELT 5 H.T.2 REF(1)	44.8	0.000	0.000	2.051
58/4-34 MELT 4 H.T.2 REF(1)	46.0	0.000	0.000	1.967
NUMBER R		5	5	5
AVG R		1.028	1.605	1.941
SUM R		5.142	8.026	9.703
SUMSQ R		5.290	12.885	18.856
SDEV R		.0198	.0144	.0836
SDEV RBAR		.0089	.0064	.0375
RED. RATIO		1.010	1.592	1.861

TABLE 13. ULTIMATE STRENGTH RATIOS FOR A357-T6 CASTING DESIGNATED AREA SUPPLIER B

			KSI	RATIO		
					e/D = 1.5	e/D = 2.0
			TUS	SUS/TUS	BUS/TUS	BUS/TUS
A86	SUPPLIER B	REF (4)	51.7	.652	0.000	2.265
A87	SUPPLIER B	REF (4)	53.7	.631	0.000	2.203
A91	SUPPLIER B	REF (4)	52.9	.647	0.000	2.233
A95	SUPPLIER B	REF (4)	53.7	.642	0.000	2.216
A99	SUPPLIER B	REF (4)	53.7	.633	0.000	2.134
B85	SUPPLIER B	REF (4)	52.7	0.000	1.753	0.000
B90	SUPPLIER B	REF (4)	52.5	0.000	1.745	0.000
B92	SUPPLIER B	REF (4)	54.3	0.000	1.720	0.000
B94	SUPPLIER B	REF (4)	54.4	0.000	1.684	0.000
B98	SUPPLIER B	REF (4)	54.1	0.000	1.675	0.000
			NUMBER R	5	5	5
			AVG R	.641	1.715	2.210
			SUM R	3.205	8.577	11.051
			SUMSQ R	2.055	14.717	24.432
			SDEV R	.0087	.0353	.0484
			SDEV RBAR	.0039	.0158	.0217
			RED. RATIO	.633	1.682	2.164

TABLE 14. ULTIMATE STRENGTH RATIOS FOR A357-T6 CASTING NONDESIG AREA SUPPLIER B

			KSI	RATIO		
					e/D = 1.5	e/D = 2.0
			TUS	SUS/TUS	BUS/TUS	BUS/TUS
F86	SUPPLIER B	REF (4)	51.3	.643	0.000	2.281
F87	SUPPLIER B	REF (4)	51.1	.673	0.000	2.305
F91	SUPPLIER B	REF (4)	52.1	.656	0.000	2.244
F95	SUPPLIER B	REF (4)	52.9	.645	0.000	2.210
F99	SUPPLIER B	REF (4)	51.1	.652	0.000	2.217
F86	SUPPLIER B	REF (4)	51.2	0.000	1.775	0.000
F87	SUPPLIER B	REF (4)	52.5	0.000	1.764	0.000
F91	SUPPLIER B	REF (4)	49.1	0.000	1.847	0.000
F95	SUPPLIER B	REF (4)	51.0	0.000	1.829	0.000
F99	SUPPLIER B	REF (4)	48.9	0.000	1.896	0.000
			NUMBER R	5	5	5
			AVG R	.654	1.822	2.251
			SUM R	3.269	9.112	11.257
			SUMSQ R	2.138	16.616	25.350
			SDEV R	.0121	.0540	.0410
			SDEV RBAR	.0054	.0242	.0183
			RED. RATIO	.642	1.771	2.212

TABLE 15. YIELD STRENGTH RATIOS FOR A357-T6 CASTING DESIGNATED AREA SUPPLIER B

			KSI	RATIO		
					e/D = 1.5	e/D = 2.0
			TYS	CYS/TYS	BYS/TYS	BYS/TYS
A86	SUPPLIER B	REF (4)	45.7	1.013	0.000	1.851
A87	SUPPLIER B	REF (4)	46.7	.972	0.000	1.850
A91	SUPPLIER B	REF (4)	46.6	.989	0.000	1.918
A95	SUPPLIER B	REF (4)	46.7	1.009	0.000	1.893
A99	SUPPLIER B	REF (4)	44.3	.995	0.000	1.851
B85	SUPPLIER B	REF (4)	46.8	0.000	1.581	0.000
B90	SUPPLIER B	REF (4)	45.4	0.000	1.593	0.000
B92	SUPPLIER B	REF (4)	48.0	0.000	1.631	0.000
B94	SUPPLIER B	REF (4)	45.2	0.000	1.615	0.000
B98	SUPPLIER B	REF (4)	44.8	0.000	1.549	0.000
			NUMBER R	5	5	5
			AVG R	.996	1.594	1.873
			SUM R	4.979	7.969	9.364
			SUMSQ R	4.958	12.705	17.540
			SDEV R	.0163	.0317	.0314
			SDEV RBAR	.0073	.0142	.0140
			RED. RATIO	.980	1.564	1.843

TABLE 16. YIELD STRENGTH RATIOS FOR A357-T6 CASTING NON-DESIGNATED AREA SUPPLIER B

			KSI	RATIO		
					e/D = 1.5	e/D = 2.0
			TYS	CYS/TYS	BYS/TYS	BYS/TYS
F86	SUPPLIER B	REF (4)	43.9	1.057	1.656	0.000
F87	SUPPLIER B	REF (4)	45.4	1.004	1.949	0.000
F91	SUPPLIER B	REF (4)	43.1	1.065	1.596	0.000
F95	SUPPLIER B	REF (4)	45.2	1.022	1.611	0.000
F99	SUPPLIER B	REF (4)	43.0	1.026	1.651	0.000
F86	SUPPLIER B	REF (4)	43.9	0.000	0.000	1.952
F87	SUPPLIER B	REF (4)	44.9	0.000	0.000	1.962
F91	SUPPLIER B	REF (4)	44.4	0.000	0.000	1.964
F95	SUPPLIER B	REF (4)	45.2	0.000	0.000	1.907
F99	SUPPLIER B	REF (4)	42.7	0.000	0.000	1.965
			NUMBER R	5	5	5
			AVG R	1.035	1.693	1.950
			SUM R	5.174	8.463	9.750
			SUMSQ R	5.357	14.411	19.016
			SDEV R	.0253	.1457	.0245
			SDEV RBAR	.0113	.0652	.0110
			RED. RATIO	1.011	1.554	1.927

TABLE 17. COMPARISON OF AVERAGE RATIOS FOR A357-T6 CASTINGS

Property Ratio	Edge Distance	Supplier A		Supplier B	
		Designated Area	Non-Designated Area	Designated Area	Non-Designated Area
		0.500 inch	0.750 inch	0.500 inch	0.750 inch
CYS/TYS		1.021	1.028	0.996	1.035
SUS/TUS		0.631	0.625	0.641	0.654
BUS/TUS	1.5	1.743	1.696	1.715	1.822
BYS/TYS	1.5	1.591	1.605	1.594	1.693
BUS/TUS	2.0	2.122	2.127	2.210	2.251
BYS/TYS	2.0	1.837	1.941	1.873	1.950

TABLE 18. REDUCED RATIOS FOR A357-6
FOR SUPPLIERS A AND B

Property Ratio	Edge Distance	Supplier A	Supplier B
CYS/TYS		1.015	0.999
SUS/TUS		0.621	0.640
BUS/TUS	1.5	1.697	1.728
BYS/TYS	1.5	1.584	1.578
BUS/TUS	2.0	2.084	2.203
BYS/TYS	2.0	1.837	1.883

TABLE 19. ULTIMATE STRENGTH RATIOS FOR A357-T6 CASTING

	KSI	RATIO		
			e/D = 1.5	e/D = 2.0
	TUS	SUS/TUS	BUS/TUS	BUS/TUS
SUPPLIER A				
DESIGNATED AREA				
2237/3-13 MELT 1 H.T. 1 REF(1)	55.3	.613	0.000	2.119
2237/3-14 MELT 1 H.T. 1 REF(1)	54.2	0.000	1.738	0.000
2244/2-17 MELT 2 H.T. 1 REF(1)	54.4	.643	0.000	1.976
2244/2-18 MELT 2 H.T. 1 REF(1)	54.6	0.000	1.753	0.000
2250/4-21 MELT 3 H.T. 1 REF(1)	54.6	.645	0.000	2.238
2250/4-22 MELT 3 H.T. 1 REF(1)	53.6	0.000	1.772	0.000
2256/4-29 MELT 5 H.T. 2 REF(1)	56.2	.616	0.000	2.132
2256/4-30 MELT 5 H.T. 2 REF(1)	54.3	0.000	1.709	0.000
2258/4-34 MELT 4 H.T. 2 REF(1)	54.8	.637	0.000	2.142
2258/4-35 MELT 4 H.T. 2 REF(1)	52.6	0.000	1.745	0.000
NON-DESIGNATED AREA				
F2237/3-13 MELT 1 H.T.1 REF( )	53.4	.618	0.000	2.122
F2237/3-13 MELT 1 H.T.1 REF( )	53.6	0.000	1.672	0.000
F2244/2-17 MELT 2 H.T.1 REF( )	55.0	.615	0.000	2.091
F2244/2-17 MELT 2 H.T.1 REF( )	52.6	0.000	1.721	0.000
F2250/4-21 MELT 3 H.T.1 REF( )	56.0	.623	0.000	2.084
F2250/4-21 MELT 3 H.T.1 REF( )	55.2	0.000	1.717	0.000
F2256/4-29 MELT 5 H.T.2 REF( )	54.8	.630	0.000	2.186
F2256/4-29 MELT 5 H.T.2 REF( )	54.1	0.000	1.641	0.000
F2258/4-34 MELT 4 H.T.2 REF( )	54.4	.642	0.000	2.153
F2258/4-34 MELT 4 H.T.2 REF( )	54.5	0.000	1.727	0.000
SUPPLIER B				
DESIGNATED AREA				
A86 SUPPLIER B REF (4)	51.7	.652	0.000	2.265
A87 SUPPLIER B REF (4)	53.7	.631	0.000	2.203
A91 SUPPLIER B REF (4)	52.9	.647	0.000	2.233
A95 SUPPLIER B REF (4)	53.7	.642	0.000	2.216
A99 SUPPLIER B REF (4)	53.7	.633	0.000	2.134
B85 SUPPLIER B REF (4)	52.7	0.000	1.753	0.000
B90 SUPPLIER B REF (4)	52.5	0.000	1.745	0.000
B92 SUPPLIER B REF (4)	54.3	0.000	1.720	0.000
B94 SUPPLIER B REF (4)	54.4	0.000	1.684	0.000
B98 SUPPLIER B REF (4)	54.1	0.000	1.675	0.000
NON-DESIGNATED AREA				
F86 SUPPLIER B REF (4)	51.3	.643	0.000	2.281
F87 SUPPLIER B REF (4)	51.1	.673	0.000	2.305
F91 SUPPLIER B REF (4)	52.1	.656	0.000	2.244
F95 SUPPLIER B REF (4)	52.9	.645	0.000	2.210
F99 SUPPLIER B REF (4)	51.1	.652	0.000	2.217
F86 SUPPLIER B REF (4)	51.2	0.000	1.775	0.000
F87 SUPPLIER B REF (4)	52.5	0.000	1.764	0.000
F91 SUPPLIER B REF (4)	49.1	0.000	1.847	0.000
F95 SUPPLIER B REF (4)	51.0	0.000	1.829	0.000
F99 SUPPLIER B REF (4)	48.9	0.000	1.896	0.000
	NUMBER R	20	20	20
	AVG R	.638	1.744	2.178
	SUM R	12.755	34.883	43.550
	SUMSQ R	8.139	60.913	94.951
	SDEV R	.0156	.0611	.0794
	SDEV RBAR	.0035	.0137	.0177
	RED. RATIO	.632	1.721	2.147

TABLE 20. YIELD STRENGTH RATIOS FOR A357-T6 CASTING

	KSI	RATIO		
			e/D = 1.5	e/D = 2.0
	TYS	CYS / TYS	BYS / TYS	BYS / TYS
SUPPLIER A				
DESIGNATED AREA				
2237/3-13 MELT 1 H.T. 1 REF(1)	47.1	1.011	0.000	1.769
2237/3-14 MELT 1 H.T. 1 REF(1)	48.7	0.000	1.548	0.000
2244/2-17 MELT 2 H.T. 1 REF(1)	47.0	1.019	0.000	1.872
2244/2-18 MELT 2 H.T. 1 REF(1)	47.5	0.000	1.598	0.000
2250/4-21 MELT 3 H.T. 1 REF(1)	48.4	1.021	0.000	1.773
2250/4-22 MELT 3 H.T. 1 REF(1)	47.7	0.000	1.589	0.000
2256/4-29 MELT 5 H.T. 2 REF(1)	47.0	1.013	0.000	1.902
2256/4-30 MELT 5 H.T. 2 REF(1)	45.4	0.000	1.634	0.000
2258/4-34 MELT 4 H.T. 2 REF(1)	48.1	1.040	0.000	1.867
2258/4-35 MELT 4 H.T. 2 REF(1)	47.1	0.000	1.586	0.000
NON-DESIGNATED AREA				
F2237/3-13 MELT 1 H.T.1 REF( )	45.5	1.015	0.000	0.000
F2244/2-17 MELT 2 H.T.1 REF( )	46.8	1.000	0.000	0.000
F2250/4-21 MELT 3 H.T.1 REF( )	46.2	1.039	0.000	0.000
F2256/4-29 MELT 5 H.T.2 REF( )	44.5	1.045	0.000	0.000
F2258/4-34 MELT 4 H.T.2 REF( )	46.6	1.043	0.000	0.000
F2237/3-13 MELT 1 H.T.1 REF( )	45.5	0.000	1.589	0.000
F2244/2-17 MELT 2 H.T.1 REF( )	44.6	0.000	1.623	0.000
F2250/4-21 MELT 3 H.T.1 REF( )	47.2	0.000	1.604	0.000
F2256/4-29 MELT 5 H.T.2 REF( )	45.1	0.000	1.594	0.000
F2258/4-34 MELT 4 H.T.2 REF( )	46.1	0.000	1.616	0.000
F2237/3-13 MELT 1 H.T.1 REF( )	44.6	0.000	0.000	1.852
F2244/2-17 MELT 2 H.T.1 REF( )	45.3	0.000	0.000	1.971
F2250/4-21 MELT 3 H.T.1 REF( )	46.8	0.000	0.000	1.861
F2256/4-29 MELT 5 H.T.2 REF( )	44.8	0.000	0.000	2.051
F2258/4-34 MELT 4 H.T.2 REF( )	46.0	0.000	0.000	1.967
SUPPLIER B				
DESIGNATED AREA				
A86 SUPPLIER B REF (4)	45.7	1.013	0.000	1.851
A87 SUPPLIER B REF (4)	46.7	.972	0.000	1.850
A91 SUPPLIER B REF (4)	46.6	.989	0.000	1.918
A95 SUPPLIER B REF (4)	46.7	1.009	0.000	1.893
A99 SUPPLIER B REF (4)	44.3	.995	0.000	1.851
B85 SUPPLIER B REF (4)	46.8	0.000	1.581	0.000
B90 SUPPLIER B REF (4)	45.4	0.000	1.593	0.000
B92 SUPPLIER B REF (4)	48.0	0.000	1.631	0.000
B94 SUPPLIER B REF (4)	45.2	0.000	1.615	0.000
B98 SUPPLIER B REF (4)	44.8	0.000	1.549	0.000
NON-DESIGNATED AREA				
F86 SUPPLIER B REF (4)	43.9	1.057	1.656	0.000
F87 SUPPLIER B REF (4)	45.4	1.004	1.949	0.000
F91 SUPPLIER B REF (4)	43.1	1.069	1.596	0.000
F95 SUPPLIER B REF (4)	45.2	1.022	1.611	0.000
F99 SUPPLIER B REF (4)	43.0	1.026	1.651	0.000
F86 SUPPLIER B REF (4)	43.9	0.000	0.000	1.952
F87 SUPPLIER B REF (4)	44.9	0.000	0.000	1.962
F91 SUPPLIER B REF (4)	44.4	0.000	0.000	1.964
F95 SUPPLIER B REF (4)	45.2	0.000	0.000	1.907
F99 SUPPLIER B REF (4)	42.7	0.000	0.000	1.965
	NUMBER R	20	20	20
	AVG R	1.020	1.621	1.900
	SUM R	20.398	32.415	38.000
	SUMSQ R	20.813	52.664	72.294
	SDEV R	.0231	.0823	.0704
	SDEV RBAR	.0052	.0184	.0158
	REQ. RATIO	1.011	1.589	1.873

TABLE 21. REDUCED RATIOS FOR A357-T6X CASTING

Mechanical Property Ratio	Edge Distance	A357-T6 Suppliers A & B	A357-T6 Boeing CAST	A357-T61 Existing MIL-HDBK-5
CYS/TYS		1.011	1.045	1.0
SUS/TUS		0.632	0.720	0.7
BUS/TUS	1.5	1.721	1.627	1.4
BYS/TYS	1.5	1.589	1.538	1.6
BUS/TUS	2.0	2.147	2.020	1.8
BYS/TYS	2.0	1.873	1.959	1.8

TABLE 22. DESIGN MECHANICAL AND PHYSICAL PROPERTIES OF A357.0 ALUMINUM ALLOY CASTING

Specification	Northrop		
Form	Casting		
Condition	T6		
Thickness, in.	≤0.500		
Location	Designated Area		Non-Designated Area
Basis	A	B	S
Mechanical properties:			
F_{tu}, ksi	50	51	45
F_{ty}, ksi	40[a]	43	36
F_{cy}, ksi	40	43	36
F_{su}, ksi	31	32	28
F_{bru}[b], ksi:			
(e/D = 1.5)	86	88	77
(e/D = 2.0)	107	109	96
F_{bry}[b], ksi:			
(e/D = 1.5)	63	68	57
(e/D = 2.0)	75	80	67
e, per cent	3	...	2
E, 10^3 ksi	10.4		
E_c, 10^3 ksi	10.5		
G, 10^3 ksi	3.9		
μ	0.33		
Physical properties:			
ω, lb/in.^{3}	0.097		
C, Btu/(lb)(F)	0.23 (at 212 F)		
K, Btu/[(hr)(ft^2)(F)/ft]	88 (at 77 F)		
α, 10^{-6} in./in./F	12.0 (68 to 212 F)		

[a]Specification value. The A-value is higher than specification values as follows: F_{ty} = 41.

[b]Bearing values are "dry pin" values per Section 1.4.7.1.

TABLE 23. TENSILE STRENGTH OF A201-T7 CASTING FROM SUPPLIER C, 0.500 INCH THICK, DESIGNATED AREA

	TYS, KSI	TUS, KSI	ELONG., %	RED., %
NO. OF DATA	51	51	51	0
AVERAGE	58.00	63.99	.75*	0.00*
STD. DEV.	3.085	2.797	.164*	0.000*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	4	5	5	0
	10	9	2	0
	5	1	0	0
	6	11	13	0
	3	2	0	0
	0	0	16	0
	4	1	0	0
	3	9	5	0
	8	9	6	0
	8	4	4	0
CHI SQUARED	15.47	29.59	53.12	9999.99
NORMAL	NO	NO	NO	NO

MIL-HDBK-5 A + B VALUES

A BASIS	0.00	0.00	0.00	0.00
B BASIS*	53.70	59.90	2.00	0.00

*Nonparametric determination.

TABLE 24. TENSILE STRENGTH OF A201-T7 CASTING FROM SUPPLIER C, 0.750 INCH THICK, NON-DESIGNATED AREA

	TYS, KSI	TUS, KSI	ELONG., %	RED., %
NO. OF DATA	32	32	32	0
AVERAGE	55.26	60.45	.65*	0.00*
STD. DEV.	2.357	2.753	.119*	0.000*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

5	5	6	0
3	1	0	0
1	3	0	0
0	2	11	0
2	3	0	0
7	6	0	0
4	4	9	C
4	2	0	0
4	3	2	0
2	3	4	0

CHI SQUARED	11.75	6.12	48.62	9999.99
NORMAL	YES	YES	NO	NO

MIL-HDBK-5 A + B VALUES

A BASIS	48.04	52.01	0.00	0.00
B BASIS	51.07	55.55	3.00	0.00

TABLE 25. TENSILE STRENGTH OF A201-T7 CASTING FROM SUPPLIER D, 0.500 INCH THICK, DESIGNATED AREA

	TYS., KSI	TUS., KSI	ELONG., %	RED., %
NO. OF DATA	52	52	52	0
AVERAGE	60.23	65.77	.75*	0.00*
STD. DEV.	1.554	1.551	.148*	0.000*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	4	3	5	0
	6	7	7	0
	3	8	2	0
	4	4	4	0
	10	7	7	0
	5	4	4	0
	6	4	5	0
	3	3	6	0
	3	7	9	0
	5	5	3	0
CHI SQUARED	7.23	6.08	7.62	9999.99
NORMAL	YES	YES	YES	NO

MIL-HDBK-5 A + B VALUES

A BASIS	55.79	61.33	2.09	0.00
B BASIS	57.68	63.22	3.17	0.00

TABLE 26. TENSILE STRENGTH OF A201-T7 CASTING FROM SUPPLIER D,
.750 max INCH THICK, NON-DESIGNATED AREA

	TYS, KSI	TUS, KSI	ELONG., %	RED., %
NO. OF DATA	33	33	33	0
AVERAGE	61.23	65.44	.52*	0.00*
STD. DEV.	1.356	1.453	.207*	0.000*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

4	4	1	0
2	2	6	0
3	3	3	0
2	3	7	0
2	3	1	0
2	5	4	0
8	3	1	0
5	1	3	0
2	6	2	0
3	3	5	0

CHI SQUARED	10.33	5.48	12.76	9999.99
NORMAL	YES	YES	YES	NO

MIL-HDBK-5 A + B VALUES

A BASIS	57.07	60.99	.77	0.00
B BASIS	58.82	62.86	1.42	0.00

TABLE 27. TESTS OF SIGNIFICANCE FOR A201-T7 CASTINGS, DESIGNATED AREA

IDENTIFICATION	TYS, KSI NUMBER	TYS, KSI AVERAGE	TYS, KSI STD.DEV.	TUS, KSI NUMBER	TUS, KSI AVERAGE	TUS, KSI STD.DEV.
A201-T7 CASTING DESIG AREA SUPPLIER C	51	58.00	3.0850	51	63.99	2.7970
A201-T7 CASTING DESIG AREA SUPPLIER D	52	60.23	1.5540	52	55.77	1.5510
T = NUMBER OF ITEMS IN GROUP		2.			2.	
DF = NUMBER OF DEGREES OF FREEDOM		101.			101.	
N = HARMONIC MEAN OF N		51.50			51.50	
DX = MAXIMUM DIFFERENCE IN AVERAGES		2.23			1.78	
WV = WEIGHTED VARIANCE		5.9309			5.0876	
WSD = WEIGHTED STANDARD DEVIATION		2.4353			2.2556	
C = BARTLETT "C"		1.0149			1.0149	
CHI SQUARED = 2.3026/C X (X1-X2) =		21.8534			15.4405	
TABULAR VALUE FOR ALPHA = .05, T-1 = 1		3.84			3.84	
THEREFORE CONCLUDE VARIANCES ARE NOT EQUAL						
Q(1-ALPHA) = DX/WSD X SQRT(N) =		6.5709			5.6630	
TABULAR VALUE FOR ALPHA = .05, T,DF= 2,101		2.81			2.81	
THEREFORE CONCLUDE AVERAGES ARE NOT EQUAL						

TABLE 28. TESTS OF SIGNIFICANCE FOR A201-T7 CASTINGS, NON-DESIGNATED AREA

IDENTIFICATION	TYS, KSI NUMBER	TYS, KSI AVERAGE	TYS, KSI STD.DEV.	TUS, KSI NUMBER	TUS, KSI AVERAGE	TUS, KSI STD.DEV.
A201-T7 CASTING NONDESIG AREA SUPPLIER C	32	55.26	2.3570	32	60.45	2.7530
A201-T7 CASTING NONDESIG AREA SUPPLIER D	33	61.23	1.3560	33	65.44	1.4530
T = NUMBER OF ITEMS IN GROUP		2.			2.	
DF = NUMBER OF DEGREES OF FREEDOM		63.			63.	
N = HARMONIC MEAN OF N		32.49			32.49	
DX = MAXIMUM DIFFERENCE IN AVERAGES		5.97			4.39	
WV = WEIGHTED VARIANCE		3.6676			4.8017	
WSD = WEIGHTED STANDARD DEVIATION		1.9151			2.1913	
C = BARTLETT "C"		1.0238			1.0238	
CHI SQUARED = 2.3026/C X (X1-X2) =		9.0076			11.8636	
TABULAR VALUE FOR ALPHA = .05, T-1 = 1		3.84			3.84	
THEREFORE CONCLUDE VARIANCES ARE NOT EQUAL						
Q(1-ALPHA) = DX/WSD X SQRT(N) =		17.7594			12.9835	
TABULAR VALUE FOR ALPHA = .05, T,DF= 2,63		2.83			2.83	
THEREFORE CONCLUDE AVERAGES ARE NOT EQUAL						

TABLE 29. TENSILE STRENGTH OF A201-T7 CASTINGS FROM SUPPLIERS C AND D, 0.500 INCH THICK, DESIGNATED AREA

	TYS, KSI	TUS, KSI	ELONG., %	RED., %
NO. OF DATA	103	103	103	0
AVERAGE	59.13	64.89	.75*	0.00*
STD. DEV.	2.671	2.416	.155*	0.000*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	15	14	10	0
	9	9	9	0
	9	6	2	0
	2	6	17	C
	6	7	7	0
	10	8	20	0
	18	16	5	0
	16	13	11	0
	9	14	15	0
	10	8	7	0
CHI SQUARED	20.40	11.05	27.39	9999.99
NORMAL	NO	YES	NO	NO

MIL-HDBK-5 A + B VALUES

A BASIS	0.00	58.40	0.00	0.00
B BASIS	54.10*	61.20	3.00	0.00

*Nonparametric determination.

TABLE 30. COMPARISON OF A AND B VALUES WITH S VALUES FROM MIL-A-21180 FOR A201-T7 CASTING

Specification	MIL-A-21180		Northrop							
Thickness, inches	All		0.500							
Supplier	All		Supplier C				Supplier D			
Class	1&2[a]	11[b]	Designated Area		Non-designated Area		Designated Area		Non-Designated Area	
Basis	S	S	A	B	A	B	A	B	A	B
Mechanical Property:										
F_{tu}	60	56	--	60[c]	52	55	61	63	61	63
F_{ty}	50	48	--	53[c]	48	51	56	57	57	58

[a]Designated area.

[b]Non-designated area.

[c]Determined by nonparametric technique.

TABLE 31. ULTIMATE STRENGTH RATIOS FOR A201-T7 CASTING, DESIGNATED AREA, SUPPLIER C

			KSI		RATIO	
					e/D = 1.5	e/D = 2.0
			TUS	SUS/TUS	BUS/TUS	BUS/TUS
A104	SUPPLIER C	REF (2)	68.8	.620	0.000	1.976
A107	SUPPLIER C	REF (2)	68.5	.601	0.000	2.038
A110	SUPPLIER C	REF (2)	69.0	.597	0.000	1.999
A113	SUPPLIER C	REF (2)	65.6	.621	0.000	2.076
B102	SUPPLIER C	REF (2)	67.2	0.000	1.417	0.000
B105	SUPPLIER C	REF (2)	65.9	0.000	1.498	0.000
B108	SUPPLIER C	REF (2)	65.4	0.000	1.543	0.000
B111	SUPPLIER C	REF (2)	67.0	0.000	1.479	0.000
B114	SUPPLIER C	REF (2)	65.5	0.000	1.582	0.000
		NUMBER R		4	5	4
		AVG R		.603	1.504	2.023
		SUM R		2.410	7.518	8.091
		SUMSQ R		1.452	11.320	16.371
		SDEV R		.0061	.0629	.0434
		SDEV RBAR		.0031	.0281	.0217
		RED. RATIO		.595	1.444	1.972

TABLE 32. ULTIMATE STRENGTH RATIOS FOR A201-T7 CASTING, NON-DESIGNATED AREA, SUPPLIER C

			KSI		RATIO	
					e/D = 1.5	e/D = 2.0
			TUS	SUS/TUS	BUS/TUS	BUS/TUS
F101	SUPPLIER C	REF (2)	58.2	.686	0.000	2.156
F104	SUPPLIER C	REF (2)	58.3	.678	0.000	2.170
F107	SUPPLIER C	REF (2)	56.0	.664	0.000	2.316
F110	SUPPLIER C	REF (2)	56.8	.694	0.000	2.217
F113	SUPPLIER C	REF (2)	60.7	.624	0.000	2.140
F101	SUPPLIER C	REF (2)	62.9	0.000	1.687	0.000
F104	SUPPLIER C	REF (2)	63.9	0.000	1.679	0.000
F107	SUPPLIER C	REF (2)	64.8	0.000	1.677	0.000
F110	SUPPLIER C	REF (2)	65.6	0.000	1.639	0.000
F113	SUPPLIER C	REF (2)	66.6	0.000	1.611	0.000
		NUMBER R		5	5	5
		AVG R		.669	1.659	2.200
		SUM R		3.345	8.293	10.999
		SUMSQ R		2.241	13.760	24.215
		SDEV R		.0272	.0325	.0710
		SDEV RBAR		.0122	.0145	.0317
		RED. RATIO		.643	1.628	2.132

TABLE 33. YIELD STRENGTH RATIOS FOR A201-T7 CASTING, NON-DESIGNATED AREA, SUPPLIER C

			KSI	RATIO	e/D = 1.5	e/D = 2.0
			TYS	CYS/TYS	BYS/TYS	BYS/TYS
A104	SUPPLIER C	REF (2)	62.7	1.041	0.000	1.707
A107	SUPPLIER C	REF (2)	62.6	1.035	0.000	1.709
A110	SUPPLIER C	REF (2)	63.1	1.038	0.000	1.645
A113	SUPPLIER C	REF (2)	62.0	1.023	0.000	1.715
B102	SUPPLIER C	REF (2)	62.6	0.000	1.436	0.000
B105	SUPPLIER C	REF (2)	62.6	0.000	1.454	0.000
B108	SUPPLIER C	REF (2)	62.4	0.000	1.444	0.000
B101	SUPPLIER C	REF (2)	62.4	0.000	1.420	0.000
B104	SUPPLIER C	REF (2)	61.1	0.000	1.419	0.000
			NUMBER R	4	5	4
			AVG R	1.034	1.435	1.694
			SUM R	4.137	7.173	6.775
			SUMSQ R	4.279	10.290	11.479
			SDEV R	.0082	.0152	.0327
			SDEV RBAR	.0041	.0068	.0164
			RED. RATIO	1.025	1.420	1.655

TABLE 34. YIELD STRENGTH RATIOS FOR A201-T7 CASTING, NON-DESIGNATED AREA, SUPPLIER C

			KSI	RATIO	e/D = 1.5	e/D = 2.0
			TYS	CYS/TYS	BYS/TYS	BYS/TYS
F101	SUPPLIER C	REF (2)	53.4	1.036	0.000	0.000
F104	SUPPLIER C	REF (2)	51.1	1.067	0.000	0.000
F107	SUPPLIER C	REF (2)	51.1	1.072	0.000	0.000
F110	SUPPLIER C	REF (2)	50.7	1.087	0.000	0.000
F113	SUPPLIER C	REF (2)	55.4	1.029	0.000	0.000
F101	SUPPLIER C	REF (2)	56.8	0.000	1.533	0.000
F104	SUPPLIER C	REF (2)	58.1	0.000	1.518	0.000
F107	SUPPLIER C	REF (2)	58.1	0.000	1.518	0.000
F110	SUPPLIER C	REF (2)	59.6	0.000	1.483	0.000
F113	SUPPLIER C	REF (2)	58.8	0.000	1.485	0.000
F101	SUPPLIER C	REF (2)	52.9	0.000	0.000	1.868
F104	SUPPLIER C	REF (2)	53.0	0.000	0.000	1.838
F107	SUPPLIER C	REF (2)	51.2	0.000	0.000	1.953
F110	SUPPLIER C	REF (2)	51.9	0.000	0.000	1.890
F113	SUPPLIER C	REF (2)	55.8	0.000	0.000	1.826
			NUMBER R	5	5	5
			AVG R	1.058	1.507	1.875
			SUM R	5.290	7.534	9.375
			SUMSQ R	5.600	11.355	17.588
			SDEV R	.0248	.0233	.0504
			SDEV RBAR	.0111	.0104	.0225
			RED. RATIO	1.034	1.485	1.827

TABLE 35. ULTIMATE STRENGTH RATIOS FOR A201-T7 CASTING, DESIGNATED AREA SUPPLIER D

			KSI		RATIO	
					e/D = 1.5	e/D = 2.0
			TUS	SUS/TUS	BUS/TUS	BUS/TUS
A201	SUPPLIER D	REF (3)	68.5	.565	0.000	2.031
A204	SUPPLIER D	REF (3)	67.2	.601	0.000	2.092
A207	SUPPLIER D	REF (3)	67.2	.594	0.000	2.137
A210	SUPPLIER D	REF (3)	69.3	.577	0.000	2.100
A213	SUPPLIER D	REF (3)	62.9	.647	0.000	2.273
B202	SUPPLIER D	REF (3)	66.5	0.000	1.671	0.000
B205	SUPPLIER D	REF (3)	69.6	0.000	1.601	0.000
B208	SUPPLIER D	REF (3)	67.2	0.000	1.645	0.000
B211	SUPPLIER D	REF (3)	67.5	0.000	1.633	0.000
B214	SUPPLIER D	REF (3)	67.8	0.000	1.643	0.000
		NUMBER R		5	5	5
		AVG R		.601	1.639	2.127
		SUM R		3.005	8.193	10.633
		SUMSQ R		1.809	13.427	22.644
		SDEV R		.0273	.0254	.0905
		SDEV RBAR		.0122	.0114	.0405
		RED. RATIO		.575	1.614	2.040

TABLE 36. ULTIMATE STRENGTH RATIOS FOR A201-T7 CASTING, NON-DESIGNATED AREA, SUPPLIER D

			KSI		RATIO	
					e/D = 1.5	e/D = 2.0
			TUS	SUS/TUS	BUS/TUS	BUS/TUS
F201	SUPPLIER D	REF (3)	63.9	.620	0.000	2.013
F204	SUPPLIER D	REF (3)	67.2	.580	0.000	1.839
F207	SUPPLIER D	REF (3)	65.5	.606	0.000	2.084
F210	SUPPLIER D	REF (3)	64.9	.615	0.000	2.008
F213	SUPPLIER D	REF (3)	65.6	.590	0.000	1.971
F201	SUPPLIER D	REF (3)	66.0	0.000	1.624	0.000
F204	SUPPLIER D	REF (3)	67.3	0.000	1.633	0.000
F207	SUPPLIER D	REF (3)	67.2	0.000	1.537	0.000
F210	SUPPLIER D	REF (3)	66.9	0.000	1.620	0.000
F213	SUPPLIER D	REF (3)	62.5	0.000	1.750	0.000
		NUMBER R		5	5	5
		AVG R		.602	1.645	1.983
		SUM R		3.011	8.225	9.915
		SUMSQ R		1.814	13.544	19.692
		SDEV R		.0166	.0605	.0901
		SDEV RBAR		.0074	.0270	.0403
		RED. RATIO		.586	1.587	1.897

TABLE 37. YIELD STRENGTH RATIOS FOR A201-T7 CASTING, DESIGNATED AREA, SUPPLIER D

			KSI	RATIO		
					e/D = 1.5	e/D = 2.0
			TYS	CYS/TYS	BYS/TYS	BYS/TYS
A201	SUPPLIER D	REF (3)	63.4	.978	0.000	0.000
A204	SUPPLIER D	REF (3)	60.8	1.044	0.000	0.000
A207	SUPPLIER D	REF (3)	60.8	1.053	0.000	0.000
A210	SUPPLIER D	REF (3)	62.7	1.024	0.000	0.000
A213	SUPPLIER D	REF (3)	56.2	1.121	0.000	0.000
B202	SUPPLIER D	REF (3)	59.2	0.000	1.542	0.000
B205	SUPPLIER D	REF (3)	63.2	0.000	1.505	0.000
B208	SUPPLIER D	REF (3)	60.2	0.000	1.543	0.000
B211	SUPPLIER D	REF (3)	60.4	0.000	1.553	0.000
B214	SUPPLIER D	REF (3)	63.1	0.000	1.509	0.000
A201	SUPPLIER D	REF (3)	63.4	0.000	0.000	1.674
A204	SUPPLIER D	REF (3)	60.8	0.000	0.000	1.872
A207	SUPPLIER D	REF (3)	60.8	0.000	0.000	1.822
A210	SUPPLIER D	REF (3)	62.7	0.000	0.000	1.864
A213	SUPPLIER D	REF (3)	56.2	0.000	0.000	2.053
			NUMBER R	5	5	5
			AVG R	1.044	1.531	1.857
			SUM R	5.220	7.653	9.285
			SUMSQ R	5.460	11.717	17.317
			SDEV R	.0519	.0215	.1357
			SDEV RBAR	.0232	.0097	.0607
			RED. RATIO	.994	1.510	1.728

TABLE 38. YIELD STRENGTH RATIOS FOR A201-T7 CASTING, NON-DESIGNATED AREA, SUPPLIER D

			KSI	RATIO		
					e/D = 1.5	e/D = 2.0
			TYS	CYS/TYS	BYS/TYS	BYS/TYS
F201	SUPPLIER D	REF (3)	61.7	.998	0.000	0.000
F204	SUPPLIER D	REF (3)	61.2	1.008	0.000	0.000
F207	SUPPLIER D	REF (3)	62.0	1.029	0.000	0.000
F210	SUPPLIER D	REF (3)	62.0	1.013	0.000	0.000
F213	SUPPLIER D	REF (3)	61.8	1.013	0.000	0.000
F201	SUPPLIER D	REF (3)	57.7	0.000	1.544	0.000
F204	SUPPLIER D	REF (3)	60.7	0.000	1.529	0.000
F207	SUPPLIER D	REF (3)	60.3	0.000	1.481	0.000
F210	SUPPLIER D	REF (3)	59.3	0.000	1.524	0.000
F213	SUPPLIER D	REF (3)	59.7	0.000	1.509	0.000
F201	SUPPLIER D	REF (3)	61.7	0.000	0.000	1.705
F204	SUPPLIER D	REF (3)	61.8	0.000	0.000	1.667
F207	SUPPLIER D	REF (3)	61.5	0.000	0.000	1.707
F210	SUPPLIER D	REF (3)	62.1	0.000	0.000	1.659
F213	SUPPLIER D	REF (3)	61.7	0.000	0.000	1.713
			NUMBER R	5	5	5
			AVG R	1.012	1.518	1.690
			SUM R	5.061	7.588	8.451
			SUMSQ R	5.124	11.517	14.286
			SDEV R	.0111	.0243	.0256
			SDEV RBAR	.0050	.0107	.0114
			RED. RATIO	1.002	1.495	1.666

TABLE 39. COMPARISON OF AVERAGE RATIOS FOR A201-T7 CASTINGS

Property Ratio	Edge Distance	Supplier C		Supplier D	
		Designated Area	Non-Designated Area	Designated Area	Non-Designated Area
		0.500 inch	0.750 inch	0.500 inch	0.750 inch
CYS/TYS		1.034	1.058	1.044	1.012
SUS/TUS		0.603	0.669	0.601	0.602
BUS/TUS	e/D = 1.5	1.504	1.659	1.639	1.645
BYS/TYS	e/D = 1.5	1.435	1.507	1.531	1.518
BUS/TUS	e/D = 2.0	2.023	2.200	2.127	1.983
BYS/TYS	e/D = 2.0	1.694	1.875	1.857	1.690

TABLE 40. REDUCED RATIOS FOR A201-T7 FOR SUPPLIERS C AND D

Property Ratio	Edge Distance	Supplier C	Supplier D
CYS/TYS		1.034	1.005
SUS/TUS		0.615	0.589
BUS/TUS	1.5	1.526	1.616
BYS/TYS	1.5	1.446	1.511
BUS/TUS	2.0	2.053	1.989
BYS/TYS	2.0	1.730	1.700

TABLE 41. ULTIMATE STRENGTH RATIOS FOR A201-T7 CASTING

			KSI	RATIO		
			TUS	SUS / TUS	e/D = 1.5 BUS / TUS	e/D = 2.0 BUS / TUS
	SUPPLIER C DESIGNATED AREA					
A104	SUPPLIER C	REF (2)	68.5	.600	0.000	1.979
A107	SUPPLIER C	REF (2)	65.9	.601	0.000	2.038
A110	SUPPLIER C	REF (2)	69.0	.597	0.000	1.999
A113	SUPPLIER C	REF (2)	65.5	.611	0.000	2.076
B102	SUPPLIER C	REF (2)	67.2	0.000	1.417	0.000
B105	SUPPLIER C	REF (2)	65.9	0.000	1.498	0.000
B108	SUPPLIER C	REF (2)	65.4	0.000	1.549	0.000
B111	SUPPLIER C	REF (2)	67.0	0.000	1.479	0.000
B114	SUPPLIER C	REF (2)	65.5	0.000	1.582	0.000
	NON-DESIGNATED AREA					
F101	SUPPLIER C	REF (2)	59.2	.686	0.000	2.155
F104	SUPPLIER C	REF (2)	58.3	.678	0.000	2.170
F107	SUPPLIER C	REF (2)	56.7	.664	0.000	2.316
F110	SUPPLIER C	REF (2)	56.8	.694	0.000	2.217
F113	SUPPLIER C	REF (2)	60.7	.624	0.000	2.140
F101	SUPPLIER C	REF (2)	62.9	0.000	1.687	0.000
F104	SUPPLIER C	REF (2)	63.9	0.000	1.679	0.000
F107	SUPPLIER C	REF (2)	66.9	0.000	1.677	0.000
F110	SUPPLIER C	REF (2)	65.6	0.000	1.639	0.000
F113	SUPPLIER C	REF (2)	66.6	0.000	1.611	0.000
	SUPPLIER D DESIGNATED AREA					
A201	SUPPLIER D	REF (3)	65.5	.585	0.000	2.031
A204	SUPPLIER D	REF (3)	67.2	.601	0.000	2.092
A207	SUPPLIER D	REF (3)	67.2	.594	0.000	2.137
A210	SUPPLIER D	REF (3)	69.3	.577	0.000	2.100
A213	SUPPLIER D	REF (3)	62.9	.647	0.000	2.273
B202	SUPPLIER D	REF (3)	66.5	0.000	1.671	0.000
B205	SUPPLIER D	REF (3)	69.6	0.000	1.601	0.000
B208	SUPPLIER D	REF (3)	67.2	0.000	1.645	0.000
B211	SUPPLIER D	REF (3)	67.8	0.000	1.633	0.000
B214	SUPPLIER D	REF (3)	67.5	0.000	1.643	0.000
	NON-DESIGNATED AREA					
F201	SUPPLIER D	REF (3)	63.9	.620	0.000	2.013
F204	SUPPLIER D	REF (3)	67.2	.580	0.000	1.839
F207	SUPPLIER D	REF (3)	65.5	.606	0.000	2.084
F210	SUPPLIER D	REF (3)	64.9	.615	0.000	2.008
F213	SUPPLIER D	REF (3)	65.6	.590	0.000	1.971
F201	SUPPLIER D	REF (3)	66.0	0.000	1.624	0.000
F204	SUPPLIER D	REF (3)	67.3	0.000	1.633	0.000
F207	SUPPLIER D	REF (3)	67.2	0.000	1.597	0.000
F210	SUPPLIER D	REF (3)	66.9	0.000	1.620	0.000
F213	SUPPLIER D	REF (3)	62.5	0.000	1.750	0.000
			NUMBER R	19	20	19
			AVG R	.620	1.611	2.086
			SUM R	11.771	32.229	39.637
			SUMSQ R	7.316	52.050	82.923
			SDEV R	.0364	.0781	.1139
			SDEV RBAR	.0083	.0175	.0261
			RED. RATIO	.605	1.581	2.041

TABLE 42. YIELD STRENGTH RATIOS FOR A201-T7 CASTING

			KSI		RATIO	
					e/D = 1.5	e/D = 2.0
			TYS	CYS/TYS	BYS/TYS	BYS/TYS
	SUPPLIER C DESIGNATED AREA					
A104	SUPPLIER C	REF (2)	52.7	1.041	0.000	1.707
A107	SUPPLIER C	REF (2)	62.6	1.035	0.000	1.709
A110	SUPPLIER C	REF (2)	63.1	1.035	0.000	1.645
A113	SUPPLIER C	REF (2)	62.0	1.023	0.000	1.715
B102	SUPPLIER C	REF (2)	62.5	0.000	1.436	0.000
B105	SUPPLIER C	REF (2)	60.6	0.000	1.454	0.000
B108	SUPPLIER C	REF (2)	62.4	0.000	1.444	0.000
B101	SUPPLIER C	REF (2)	62.4	0.000	1.420	0.000
B104	SUPPLIER C	REF (2)	61.1	0.000	1.419	0.000
	NON-DESIGNATED AREA					
F101	SUPPLIER C	REF (2)	53.4	1.036	0.000	0.000
F104	SUPPLIER C	REF (2)	51.1	1.067	0.000	0.000
F107	SUPPLIER C	REF (2)	51.1	1.072	0.000	0.000
F110	SUPPLIER C	REF (2)	50.7	1.087	0.000	0.000
F113	SUPPLIER C	REF (2)	55.4	1.029	0.000	0.000
F101	SUPPLIER C	REF (2)	56.9	0.000	1.533	0.000
F104	SUPPLIER C	REF (2)	55.1	0.000	1.513	0.000
F107	SUPPLIER C	REF (2)	58.1	0.000	1.518	0.000
F110	SUPPLIER C	REF (2)	59.6	0.000	1.480	0.000
F113	SUPPLIER C	REF (2)	55.8	0.000	1.485	0.000
F101	SUPPLIER C	REF (2)	52.9	0.000	0.000	1.868
F104	SUPPLIER C	REF (2)	53.0	0.000	0.000	1.838
F107	SUPPLIER C	REF (2)	51.2	0.000	0.000	1.953
F110	SUPPLIER C	REF (2)	51.9	0.000	0.000	1.890
F113	SUPPLIER C	REF (2)	55.5	0.000	0.000	1.826
	SUPPLIER D DESIGNATED AREA					
A201	SUPPLIER D	REF (3)	63.4	.978	0.000	0.000
A204	SUPPLIER D	REF (3)	60.8	1.044	0.000	0.000
A207	SUPPLIER D	REF (3)	60.5	1.053	0.000	0.000
A210	SUPPLIER D	REF (3)	62.7	1.024	0.000	0.000
A213	SUPPLIER D	REF (3)	56.2	1.121	0.000	0.000
B202	SUPPLIER D	REF (3)	59.2	0.000	1.542	0.000
B205	SUPPLIER D	REF (3)	63.2	0.000	1.505	0.000
B208	SUPPLIER D	REF (3)	60.2	0.000	1.543	0.000
B211	SUPPLIER D	REF (3)	60.6	0.000	1.553	0.000
B214	SUPPLIER D	REF (3)	63.1	0.000	1.509	0.000
A201	SUPPLIER D	REF (3)	63.4	0.000	0.000	1.674
A204	SUPPLIER D	REF (3)	60.5	0.000	0.000	1.872
A207	SUPPLIER D	REF (3)	60.8	0.000	0.000	1.822
A210	SUPPLIER D	REF (3)	62.7	0.000	0.000	1.864
A213	SUPPLIER D	REF (3)	56.2	0.000	0.000	2.053
	NON-DESIGNATED AREA					
F201	SUPPLIER D	REF (3)	61.7	.999	0.000	0.000
F204	SUPPLIER D	REF (3)	61.2	1.008	0.000	0.000
F207	SUPPLIER D	REF (3)	62.0	1.029	0.000	0.000
F210	SUPPLIER D	REF (3)	62.0	1.013	0.000	0.000
F213	SUPPLIER D	REF (3)	61.5	1.013	0.000	0.000
F201	SUPPLIER D	REF (3)	57.7	0.000	1.544	0.000
F204	SUPPLIER D	REF (3)	60.7	0.000	1.529	0.000
F207	SUPPLIER D	REF (3)	60.9	0.000	1.481	0.000
F210	SUPPLIER D	REF (3)	59.3	0.000	1.524	0.000
F213	SUPPLIER D	REF (3)	59.7	0.000	1.509	0.000
F201	SUPPLIER D	REF (3)	61.7	0.000	0.000	1.705
F204	SUPPLIER D	REF (3)	61.9	0.000	0.000	1.667
F207	SUPPLIER D	REF (3)	61.5	0.000	0.000	1.707
F210	SUPPLIER D	REF (3)	62.1	0.000	0.000	1.659
F213	SUPPLIER D	REF (3)	61.7	0.000	0.000	1.713
			NUMBER R	19	20	19
			AVG R	1.037	1.497	1.783
			SUM R	19.709	29.949	33.886
			SUMSQ R	20.453	44.879	60.670
			SDEV R	.0329	.0429	.1141
			SDEV RBAR	.0075	.0096	.0262
			RED. RATIO	1.024	1.481	1.736

TABLE 43. REDUCED RATIOS FOR A201-T7 CASTING

Property Ratio	Edge Distance	Suppliers C & D A201-T7	Existing MIL-HDBK-5 A201-T6
CYS/TYS		1.024	1.02
SUS/TUS		0.605	0.62
BUS/TUS	1.5	1.581	1.50
BYS/TYS	1.5	1.481	1.54
BUS/TUS	2.0	2.041	1.92
BYS/TYS	2.0	1.738	1.80

```
            TENSILE ULTIMATE STRENGTH

                              10        20        30        40        50
    STRESS       ---------V---------V---------V---------V---------V

        45       *
        46
        47       **
        48       *
        49       ****
        50       ****
        51       ***********
        52       *****
        53       ****
```

FIGURE 1. HISTOGRAM FOR A357-T6 TENSILE ULTIMATE STRENGTH DATA FOR NON-DESIGNATED AREA - SUPPLIER B

TENSILE YIELD STRENGTH

```
                  10        20        30        40        50
STRESS   ---------V---------V---------V---------V---------V
   54    ********
   55    *******
   56    ****
   57    *********
   58
   59    ****
   60    **
   61    *********
   62    ***
   63    *****
```

TENSILE ULTIMATE STRENGTH

```
                  10        20        30        40        50
STRESS   ---------V---------V---------V---------V---------V
   60    *****
   61    *********
   62    *
   63    ************
   64    *
   65    *
   66    *********
   67    *********
   68
   69    ****
```

FIGURE 2. HISTOGRAMS FOR A201-T7 TENSILE YIELD AND ULTIMATE STRENGTH DATA FROM SUPPLIER C DESIGNATED AREA

```
TENSILE YIELD STRENGTH

                  10        20        30        40        50
STRESS   ---------V---------V---------V---------V---------V
  54     ********
  55     *******
  56     ******
  57     **********
  58     ***
  59     ***********
  60     *********************
  61     *******************
  62     ********
  63     **********
```

```
TENSILE ULTIMATE STRENGTH

                  10        20        30        40        50
STRESS   ---------V---------V---------V---------V---------V
  60     *****
  61     *********
  62     *
  63     **************
  64     *********
  65     **************
  66     *********************
  67     ******************
  68     *****
  69     ******
  70     *
```

FIGURE 3. HISTOGRAMS FOR A201-T7 TENSILE YIELD AND ULTIMATE STRENGTH DATA FROM SUPPLIERS C AND D DESIGNATED AREA

APPENDIX E

QUALIFIED FOUNDRY PROCESSES

QUALIFIED FOUNDRY PROCESSES

Magnesium Alloy Products (A357-T6 Alloy):

The following controls and procedures wEere sed to cast the step plates for program evaluation at Magnesium Alloy Products:

Chemistry Control

1. Use a metal charge of ingot and back scrap that is made for Magnesium Alloy Products limits per form L-9 (8/76)

2. Pour preliminary chemical samples (prior to final grain refiner additions) to check chemistry to Magnesium Alloy Products limits

3. Pour a final chemical sample after final grain refiner additions are made

Gas Control

1. Degass melt by bubbling pure and dry nitrogen (approximately 45 minutes for 300 lbs melt)

2. Check gas content of melt under vacuum, with maximum of eight bubbles, obtain approval prior to adding final grain refiner

Grain Size

Control grain size by adding final grain refiner of 0.2 percent to 0.6 percent of titanium within one hour of pour-off

Melt Temperature

1. Control temperature during processing with automatic furnace controls

2. Control pour-off temperature to within $\pm$ 20F of the specified temperature: 1380F for a stepped panel and 1240F for a K_{Ic} block

Molding (Figure E1)

1. Use conventional green molding (oil bonded petro bond sand)

2 Use the following aluminum chills:

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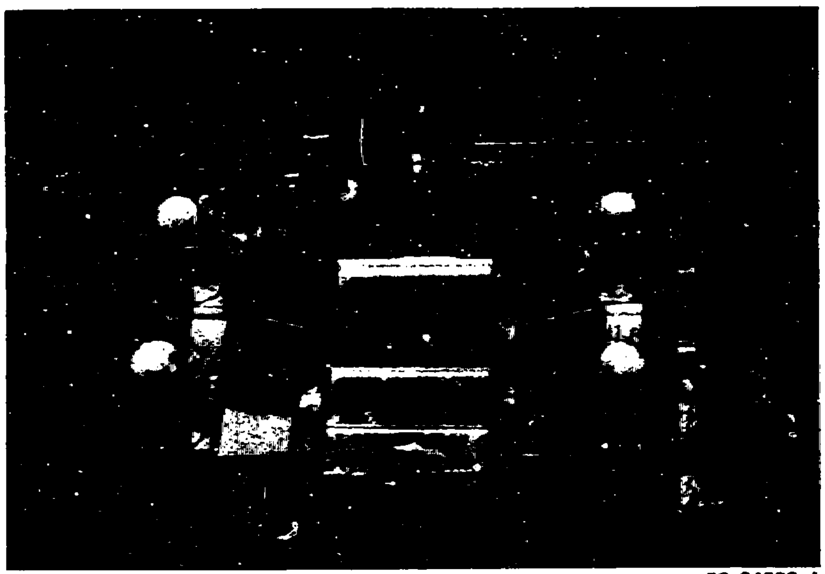

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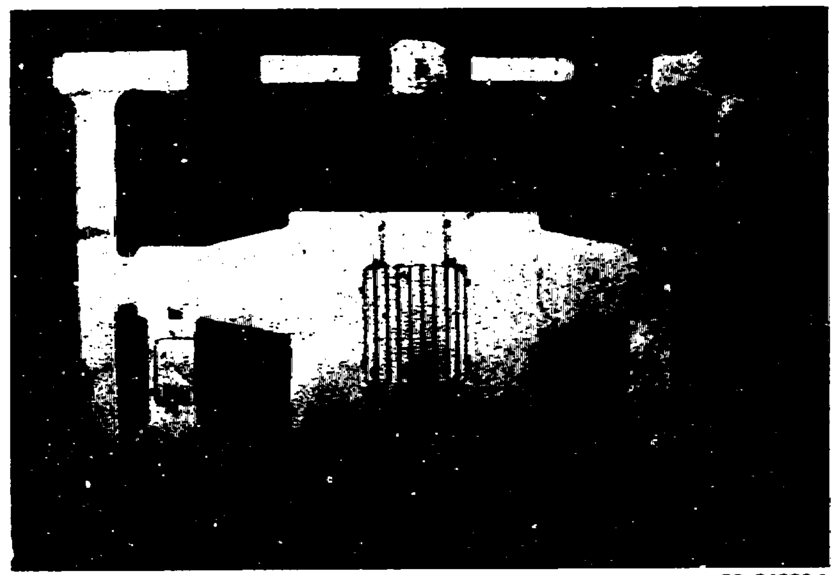

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FIGURE E-1. RIGGING AND CHILLING OF STEP PLATE CASTING PRODUCED BY MAGNESIUM ALLOY PRODUCTS CO.

Mold	Quantity	Size (Inch)
Drag half	1	3 x 3-1/2 x 2-1/2
	2	2 x 2 x 1-1/2
	1	1-1/2 x 2 x 3/4
	Coupon "A"	2 x 1-1/4 x 2
Cope half	3	Form chills
	1	3 x 1-1/2 x 2-1/2
	Coupon "A"	1 x 1-1/4 x 1-1/2

3. Use a 1 x 3/8 inch, tapered sprue
4. Use two 2-1/2 x 4-1/2 inch fiberglass screens
5. Use a flask with a 6-inch cope and 6-inch drag.

Welding

1. Accomplish welding per Magnesium Alloy Products weld procedure, as authorized

Heat Treatment

1. Apply solution heat treatment at 1010F $\pm$ 10F for a minimum of 12 hours
2. Ensure load density during solution heat treatment is light, castings are spaced apart, and temperature rise of quench water is less than 15F
3. Maintain quench temperature by using room temperature water at 60F to 80F with adequate water circulation, for a period of less than 8 seconds
4. Apply precipitation heat treatment at 330F $\pm$ 5F for 5 to 7 hours to achieve a yield of 44,000 $\pm$ 1,000 in integral coupons

<u>Teledyne Cast Products</u> (A357-T6 Alloy):

The following control procedures were developed at Teledyne Cast Products for production of step plates:

Melting

The following procedure for PQ A357 alloy is used in conjunction with the Teledyne Cast Products Standard Practice #6306:

1. Use charge consisting of 100 percent A357 ingot in gas-fired furnace with silicon crucible
2. Melt down metal charge; add No. 11 coverall as metal begins to melt

3. Adjust temperature to 1300F; keep surface covered with No. 11 cover-all as metal is melting

4. Roll melt carefully to obtain good mix action, breaking the metal surface as little as possible

5. Pour chemical slug; start heating titanium-boron hardener on furnace setting (1/2 lb per 100 lb of melt)

6. Time to coincide (within one hour) with the completion of mold assembly; perform the following steps through approval of melt

7. Adjust metal temperature to 1350F; skim

8. Add alloy ingredients in accordance with standard practice (do not add titanium-boron hardener unless specified by laboratory to bring titanium up to chemical requirements)

9. Adjust temperature to 1380F; degas with nitrogen for 20 minutes; take chemical slug; let melt settle for five minutes; set temperature for 1300F

10. Take gas analysis sample at 10 mm. vacuum; if gassy, repeat step 9

11. If gas is acceptable, raise melt temperature to 1350F and add titanium-boron hardener.

12. Preheat ladles

13. Skim, fill ladle, skim ladle, and pour at 1350F $\pm$ 20F.

Chemistry

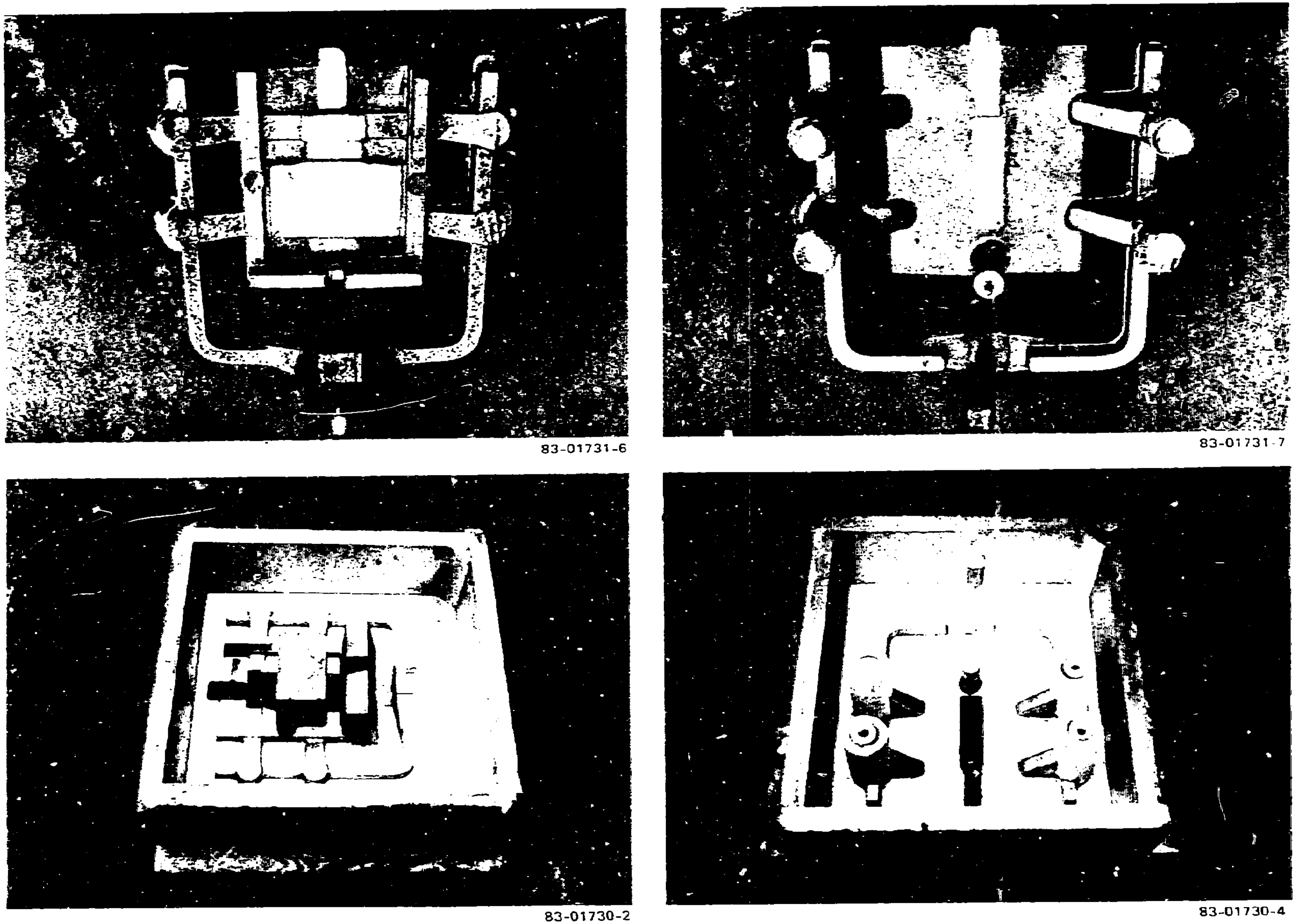
A357 alloy chemistry after degassing (step 9 of melt procuedure, above, is as follows:

Iron	0.10 maximum
Magnesium	0.55 to 0.590
Beryllium	0.055 to 0.075 (optimum 0.065)
Titanium	0.12 minimum
Balance to meet specification.	

Final chemistry is the same as listed above.

Molding (Figure E-2)

Use AFS 60 Nevada molding sand hardened with 1.1 percent Pepset binder (photographs indicate mold assembly)



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83-01731-7

83-01730-2

83-01730-4

FIGURE E-2. RIGGING AND CHILLING PROCEDURE OF TEST PLATES
CAST AT TELEDYNE CASTING COMPANY

Heat Treatment

1. Apply solution heat treatment at 1010F for 16 hours

2. Use water quench procedure

3. Follow step 2 with a 24-hour delay at room temperature and a 6-hour age treatment at 340F $\pm$ 10F.

Smithford Products Co. (A201 Alloy)

The following control procedures were applied to produce test step plates at Smithford Products:

Melting

The melting process is as follows:

1. Accomplish melting in a 1000lb gas-fired furnace with a silicon-carbide crucible.

2. Use a charge of approximately 60 percent ingot and 40 percent returns, which are cleaned and from which all metallic screens are removed

3. Degas the melt by an injection of nitrogen and chlorine gas until a sample, solidified under a vacuum of 2 to 4 inches of mercury, shows no evidence of gas when sectioned and polished

4. After completing degassing, adjust the melt to proper composition and checked again for gas content

5. Increase temperature raised to 1390F and make a final check made for composition; add grain refiner salt (titanium-boron) within 30 minutes prior to pour

6. If composition is acceptable, pour melt.

Materials used for melt addition are as follows:

1. Copper in wire form
2. Tital 6 percent (titanium-aluminum)
3. Magnesium in stock form
4. Silver in granule form.
5. Manganese (10 percent) in button form
6. 201 refining salt (Titanium-Boron)

Melt chemistry is adjusted to target ranges of the following:

	Content	Percent
1.	Copper	4.70 to 4.90
2.	Silver	0.50 to 0.60
3.	Magnesium	0.30 to 0.35.

The balance of the composition is controlled to specification limits.

Molding

The castings are produced in a match pattern in dry sand molds of AFS No. 70 sand, using a 1.5 percent "pepset" binder. The rigging and chilling system is shown in Figure E-3

Solution Heat Treatment

The step plates are located in a basket on an edge approximately one inch apart. The following procedure was used:

1. Apply solution heat treatment, using a gas-fired furnace, as follows:
   - o 1 hour at 940F
   - o 1 hour at 960F
   - o 12 hours at 980F
2. Quenched in room temperature water with a 7-to-10 second delay
3. After an age delay of 12 to 24 hours artificially age at 370F for 5 hours.

<u>Morris Bean Foundry</u> (A201 Alloy)

The following procedures were used for control of foundry processing of step plate castings at Morris Bean and Company. The melting practice is as follows:

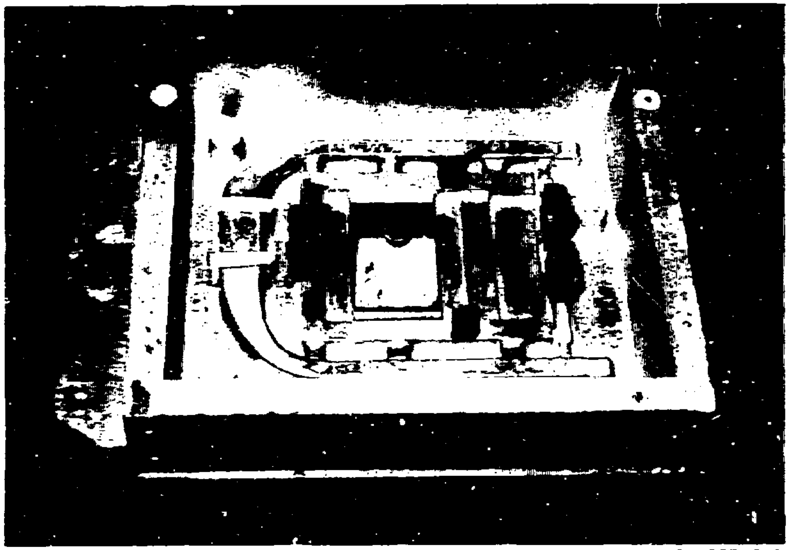
Melting

The melting practice is as follows:

1. Use an A201 ingot and a maximum of 20 percent clean remelt as base charge
2. Control magnesium by using 100 percent magnesium alloy
3. Add copper by using electrical grade copper wire
4. Use silver in ingot form to maintain specifications
5. Add titanium as 5 percent titanium - 1 percent beryllium hardener in the form of as extruded rod.

The melting procedure is as follows:

1. Melt ingot down
2. Heat at 780C to 790C
3. Degas with nitrogen for 15 minutes for graphite diffusion head
4. Obtain chemical check specimen



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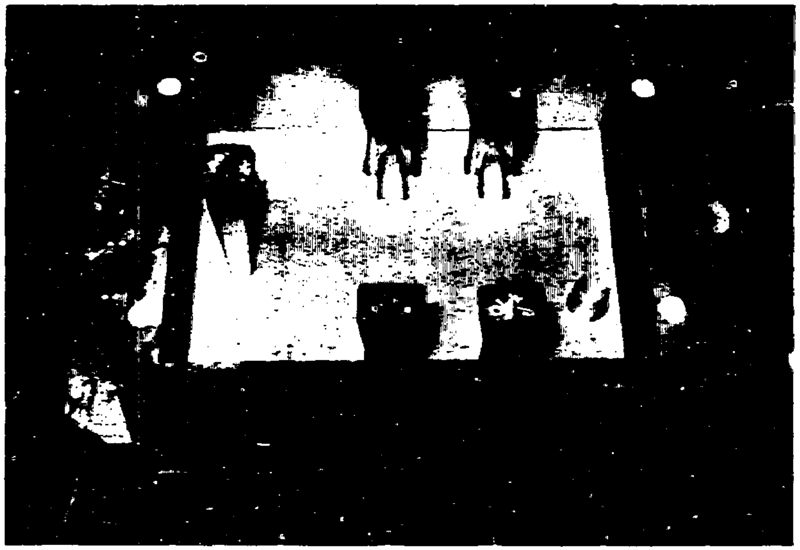

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ALL ALUMINUM CHILLS USED.

FIGURE E-3. RIGGING AND CHILLING PROCEDURE FOR SMITHFORD CAST TEST PLATES

5. Adjust chemical composition to the following:

Content	Percent
Copper	4.5 to 5.0
Silver	0.5 to 1.0
Manganese	0.2 to 0.5
Magnesium	0.25 to 0.35
Titanium	0.15 to 0.30
Iron	0.05 maximum
Zinc	0.10 maximum
Silicon	0.10 maximum
Nitrogen	0.05 maximum
Others	0.05 maximum
Other total	0.15 maximum

6. Degas again for 15 minutes
7. Obtain chemical check specimen again
8. Pour gas slab for gas check
9. Add 5 percent titanium - 1 percent beryllium grain refine (0.002% Ti B rod)
10. Wait for 10 minutes after stirring
11. Pour step plates at 760C - 770C.

Melt controls are as follows:

Gas control:

1. Degas with Argon-Freon gas mixture for 15 minutes; complete degassing using argon gas in electric ladle

2. Pour reduced pressure button to evaluate gas level

3. When gas level is satisfactory, pour x-ray gas slab to verify melt is gas free (slab should not exceed No. 1 gas level; when gas slab is acceptable, melt is ready to pour.

Grain Size

1 Maintain grain size by refining with KBI A201 salt flux prior to pouring (flux addition is 1/4 percent of melt weight)

Solution Heat Treatment

1. Apply solution heat treatment as follows:

Temperature, °F	Time, Hours
920	2
940	2
960	2
980 ± 10	18

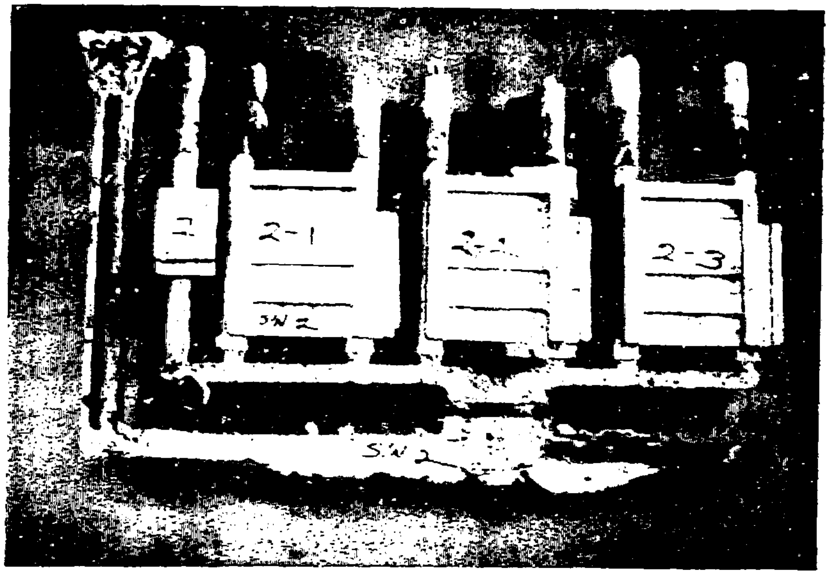
2. Quenched castings by hand removing from furnace on a wire quenching in room temperature water (quench time is 6-10 seconds)

3. Age delay at room temperature for a minimum of 12 hours

4. Age plates at 370F ± 5F for 4 to 5 hours.

Molding Procedure

All castings were poured in dry sand cheek molds which used a Pepset binder. The mold assembly is shown in Figure E-4.



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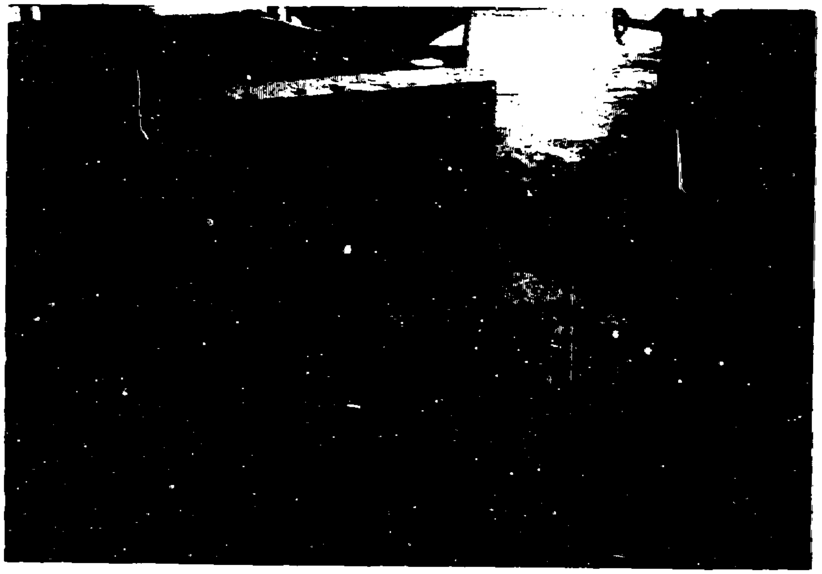

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FIGURE E-4. RIGGING AND CHILLING PLACEMENT FOR STEP PLATES CAST BY MORRIS BEAN AND COMPANY

APPENDIX F

EVALUATION REPORT - FATIGUE CRACK GROWTH TESTING OF CAST ALUMINUM ALLOY A357-T6

SYSTEMS SUPPORT DIVISION
AFWAL MATERIALS LABORATORY
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

EVALUATION REPORT

FATIGUE CRACK GROWTH TESTING OF CAST ALUMINUM ALLOY A357-T6

REPORT NR: MLS-84-37

DATE: 25 Apr 84

PROJECT NR: 24180703

TYPE EVALUATION: Constant-Load-Amplitude Fatigue Crack Growth Tests

MANUFACTURERS: Teledyne Cast Products
Magnesium Alloy Products Co.

SPEC NR: N/A

REQUESTED BY: Northrop Corporation
ATTN: Mr Kermit J. Oswalt
Metallic Materials Research
Advanced Manufacturing Technology
Orgn 3872/62, Aircraft Division
One Northrop Avenue
Hawthorne CA 90250

ITEM SERIAL NR: N/A

WUD NR: N/A

I. PURPOSE

To generate constant-load-amplitude fatigue crack growth data for cast aluminum A357-T6.

II. BACKGROUND

A357 is a heat-treatable, aluminum-silicon-magnesium casting alloy which has moderate mechanical properties in the -T6 condition. Although many aerospace components have been cast with A357, the alloy still lacks a comprehensive statistically analyzed data base. Without this data, which includes damage tolerance critical data, A357 is generally specified for non-flight-critical structures and components. Both the aerospace industry and the Air Force realize that eliminating this data void will lead to greater use of A357 castings and substantial cost savings.

As a major step in developing such data, the Northrop Corporation, under Air Force contract, is generating supplementary MIL-HDBK-5 data for casting alloys A357 and A201. A part of this program involves obtaining A357 test plate castings from several sources, expanding the existing data base, and eventually deriving design allowables. To assist this effort, the Systems Support Division (AFWAL/MLSE) agreed to conduct fatigue crack growth testing of A357 in exchange for A357 step plates. These step plates will be part of a future in-house program to characterize A357 at elevated temperature. This report describes the fatigue crack growth testing performed, and the results obtained for A357 at room temperature.

III. MATERIALS AND SPECIMENS

Twelve A357-T6 fatigue crack growth specimens were supplied to Systems Support Division by Northrop. The specimens tested were standard compact-type (CT) specimens, measuring 0.375 inches thick (B) and 2.000 inches wide (W).

Alloy chemistry was within the following limits for nine of the twelve specimens:

Silicon	6.5 - 7.5%
Magnesium	0.55 - 0.65%
Iron	0.20% max
Titanium	0.10 - 0.20%
Beryllium	0.04 - 0.07%
Zinc	0.10% max
Copper	0.20% max
Manganese	0.10% max
Aluminum	Balance

Table I lists information about each specimen. Specimen 89CG1 LowSi was tested before the silicon deficiency in three of the specimens was discovered.

IV. TEST PROCEDURES

Tests were conducted in accordance with ASTM E647, "Standard Test Method for Constant-Load-Amplitude Fatigue Crack Growth Rates Above 10^{-8}m/cycle."

Specimens were precracked and tested on a 2.2 kip electrohydraulic axial fatigue machine. Crack length was measured with a Fractomat electronic crack length reading system. Electronic measurements were verified with a traveling microscope.

An R ratio of 0.1 was applied sinusoidally at 25 Hz for three specimens, and 30 Hz for nine specimens.

All tests were conducted at room temperature in lab air.

V. TEST RESULTS AND DISCUSSION

The fatigue crack growth results for each test were plotted in Figures 1-10. For ease of comparison, Figures 11-14 were also generated.

Of the six specimens from Magnesium Alloy Products Co. tested, two (36CG1, 251/4-31) deviated considerably from the other four at low ΔKs. At approximately 11 KSI $\sqrt{in}$ and above, all of the Magnesium Alloy Co. plots assume the same form and exhibit little scatter (Figure 11 - 12).

The Teledyne specimen plots revealed greater scatter as shown in Figure 13. At low ΔKs specimen 89CG1 had the least crack growth resistance while specimen 97CG1 had the most crack growth resistance. The low silicon specimen plot (Figure 10) was in line with the other Teledyne plots.

The plot in Figure 14 was generated for comparison with the data generated in this study. The Magnesium Alloy Co. and Teledyne material both possessed better crack growth resistance at low ΔKs than 2124-T851 and A201-T7. Also, it was noticed that the fatigue crack growth rates obtained in this program were similar to those generated in the CAST program.

VI. CONCLUSIONS

Cast A357-T6 is competitive with some commonly used wrought alloys when considering fatigue crack growth resistance, especially at low ΔK values.

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Systems Support Division	Systems Support Division

PUBLICATION REVIEW

This report has been reviewed and approved by:

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Materials Engineering Branch
Systems Support Division
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AFWAL/TSTM
AFWAL/MLS
AFWAL/MLSE (T. Reinhart)
AFWAL/MLSA (T. Cooper)
AFWAL/MLSS (Maj Hardy)
Northrop Corp. (Kermit Oswalt)
Northrop Corp. (Yuli Lii)

TABLE I: Specimen data.

SPECIMEN	MANUFACTURER	COMMENT
15CG1	Magnesium Alloy	MT 1/
36CG1	Magnesium Alloy	MT
37CG1	Magnesium Alloy	MT
80CG1 LowSi	Teledyne	Low Si, NT 2/
89CG1 LowSi	Teledyne	Low Si, ET 3/
97CG1 LowSi	Teledyne	Low Si, NT
244/2-19	Magnesium Alloy	ET
250/4-24	Magnesium Alloy	ET
251/4-31	Magnesium Alloy	ET
89CG1	Teledyne	Replaced 80CG1 LowSi, ET
93CG1	Teledyne	Replaced 89CG1 LowSi, ET
97CG1	Teledyne	Replaced 97CG1 LowSi, ET

1/ MT = Manual Test
2/ NT = No Test
3/ ET = Electronic Test

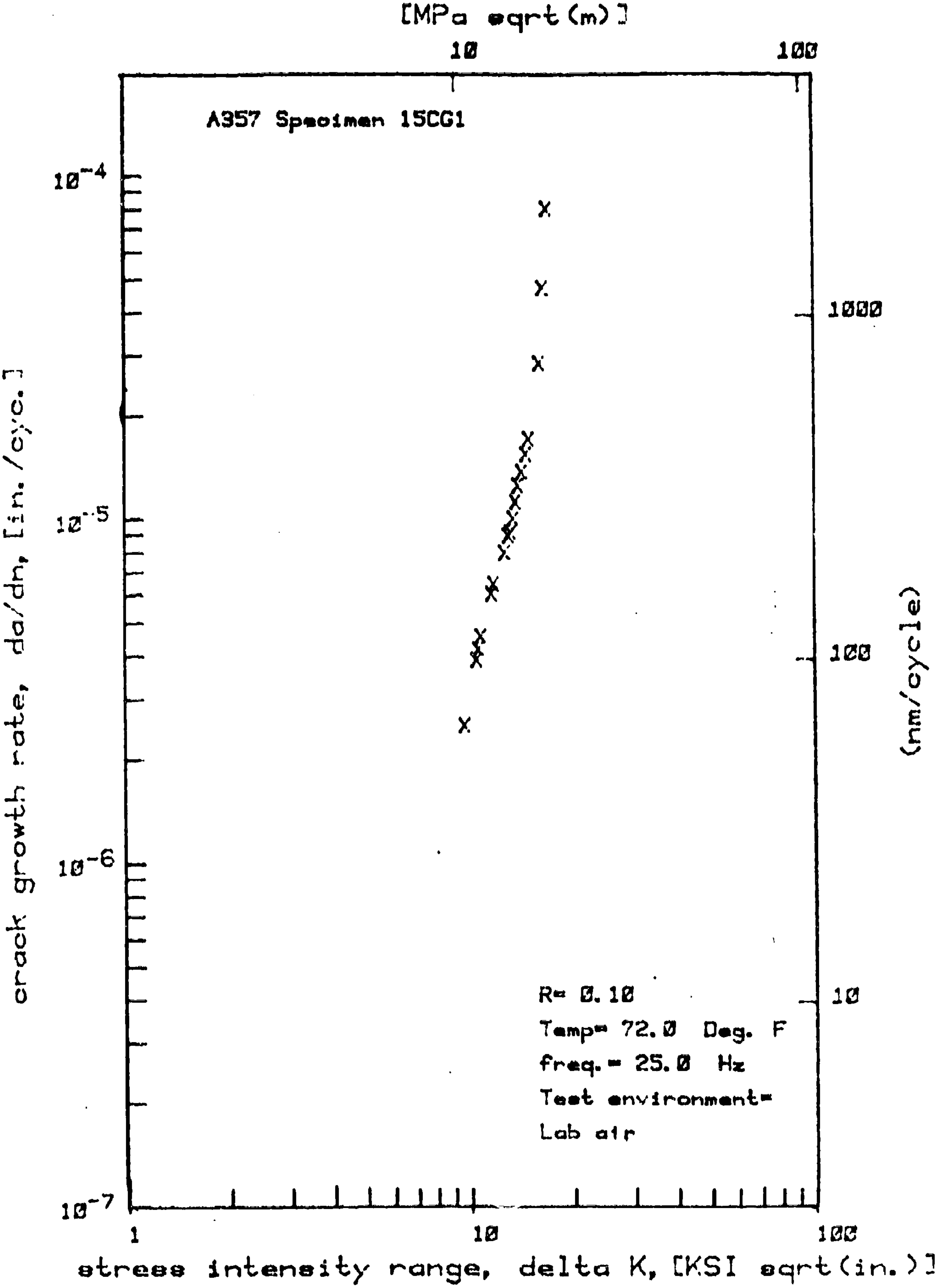

Figure 1. Fatigue crack growth plot of A357-T6 Specimen 15CG1.

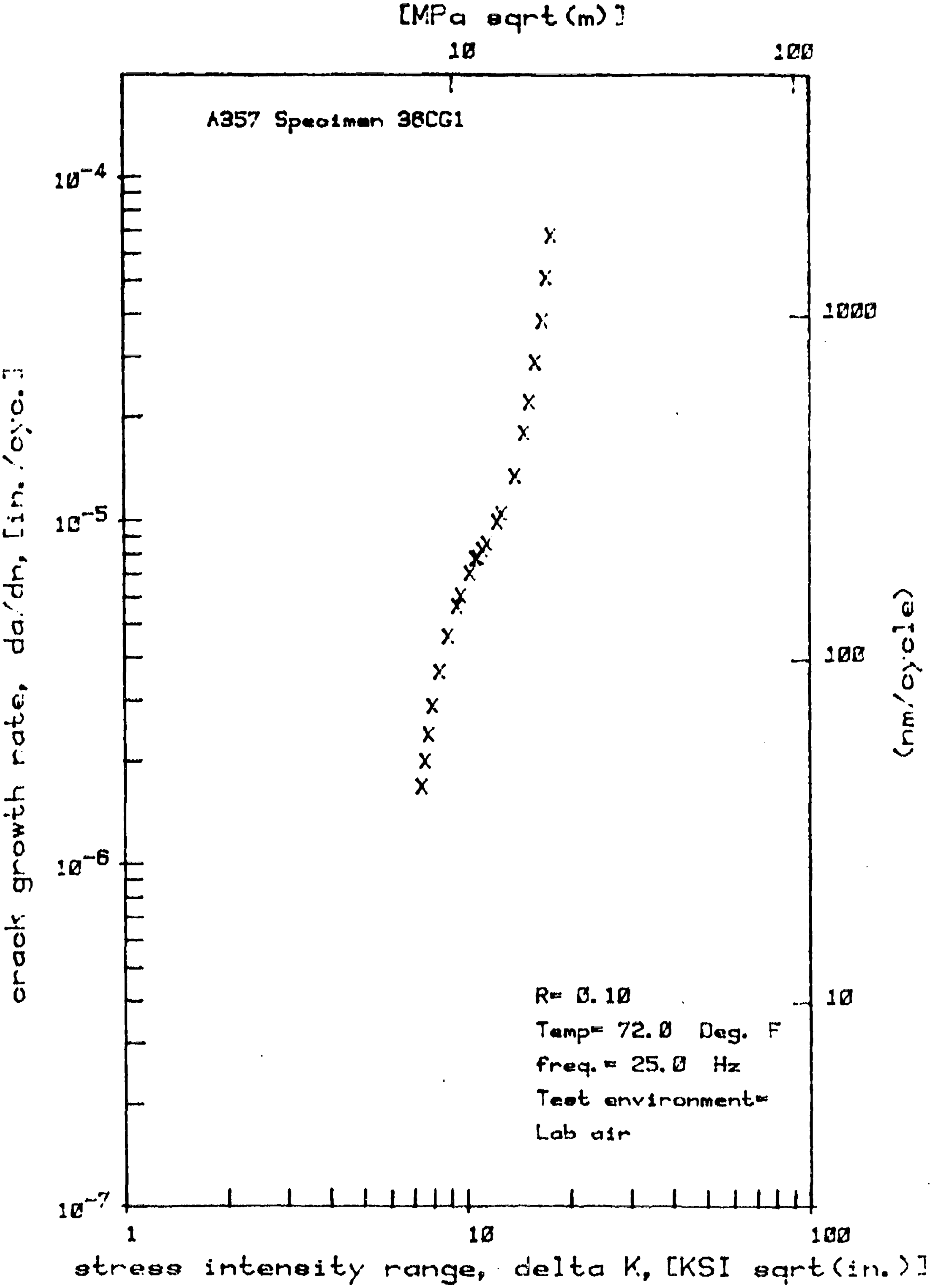

Figure 2. Fatigue crack growth plot of A357-T6 Specimen 36CG1.

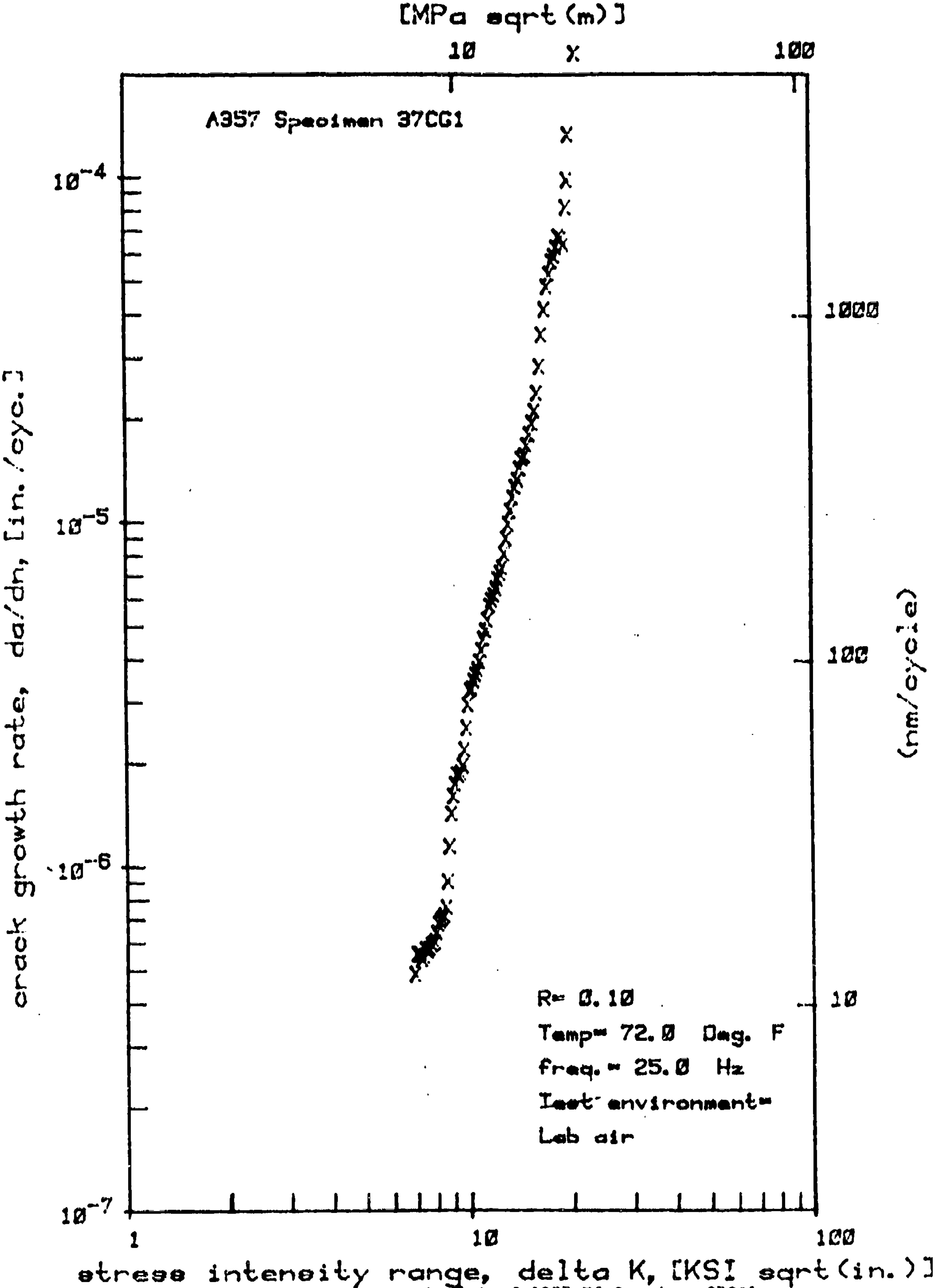

Figure 3. Fatigue crack growth plot of A357-T6 Specimen 37CG1.

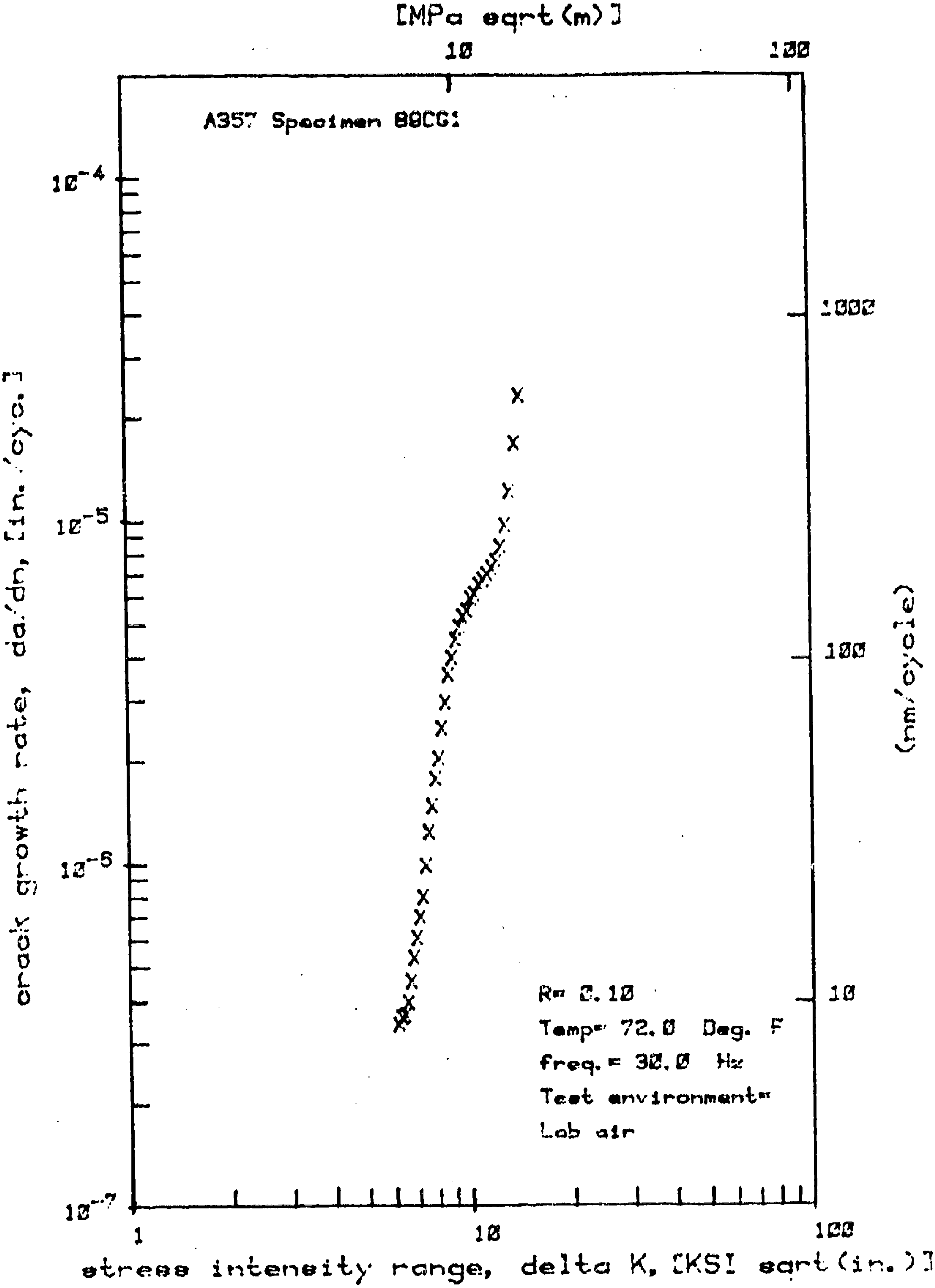

Figure 4. Fatigue crack growth plot of A357-T6 Specimen 89CG1.

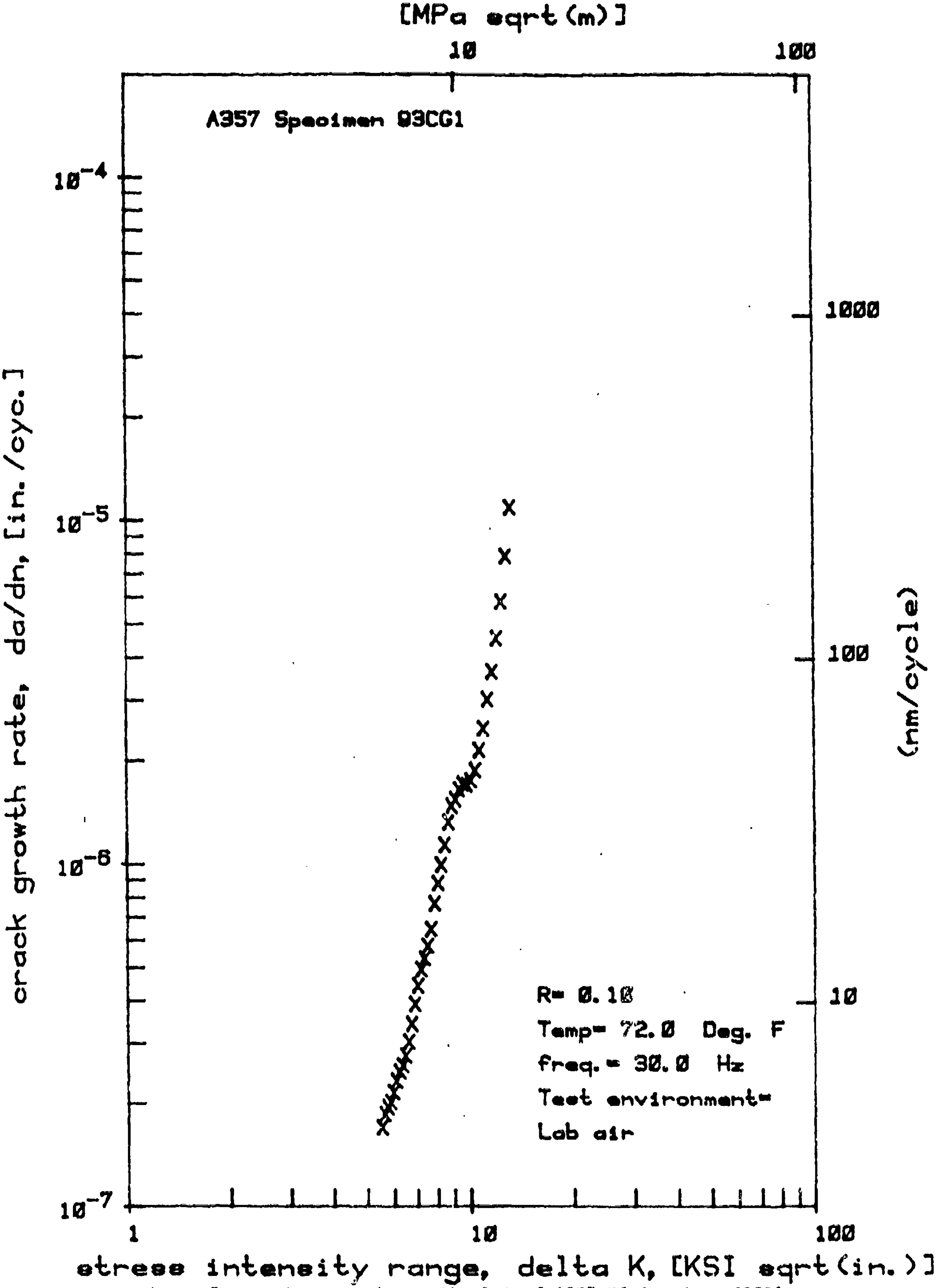

Figure 5. Fatigue crack growth plot of A357-T6 Specimen 93CG1.

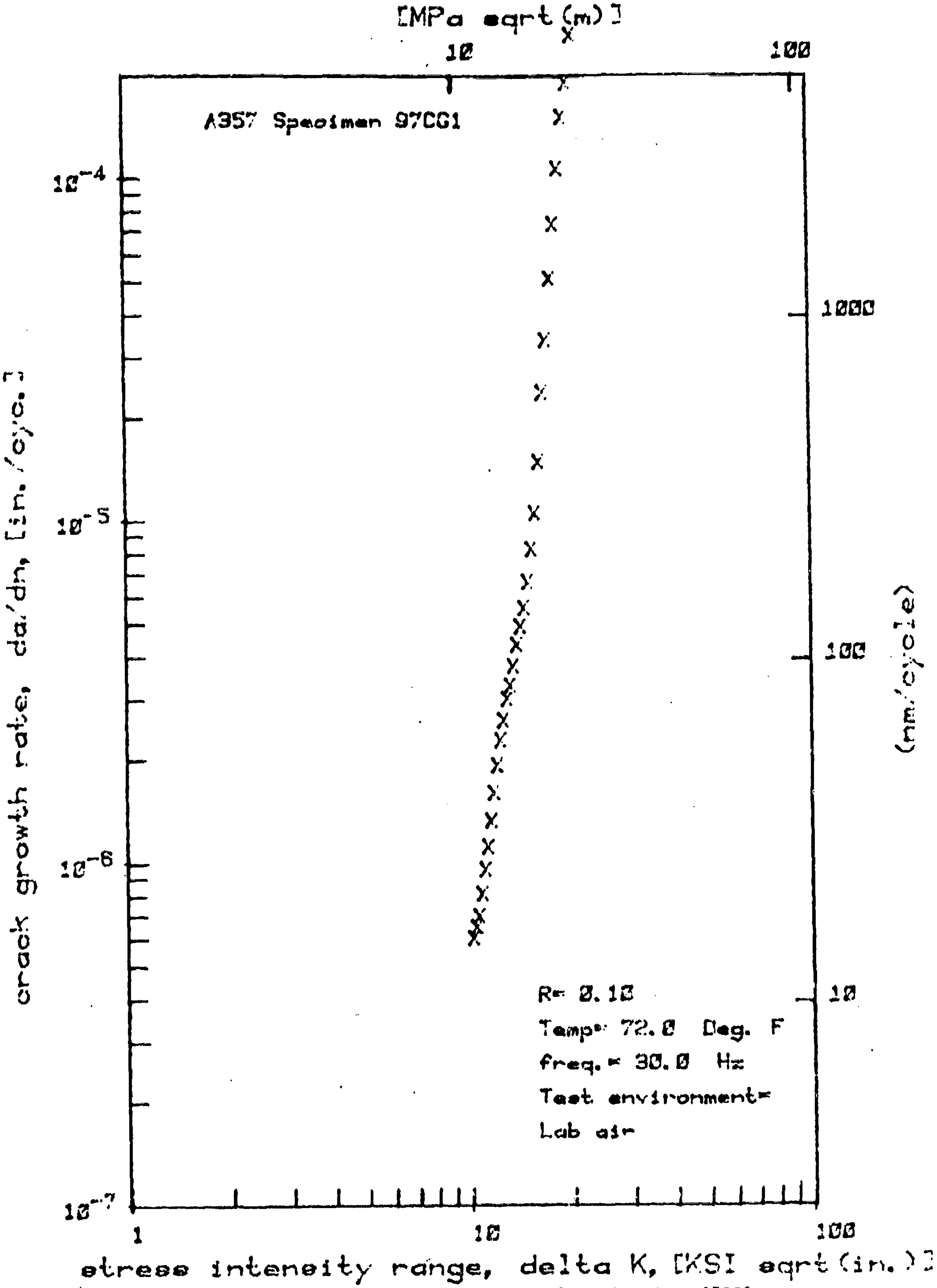

Figure 6. Fatigue crack growth plot of A357-T6 Specimen 97CG1.

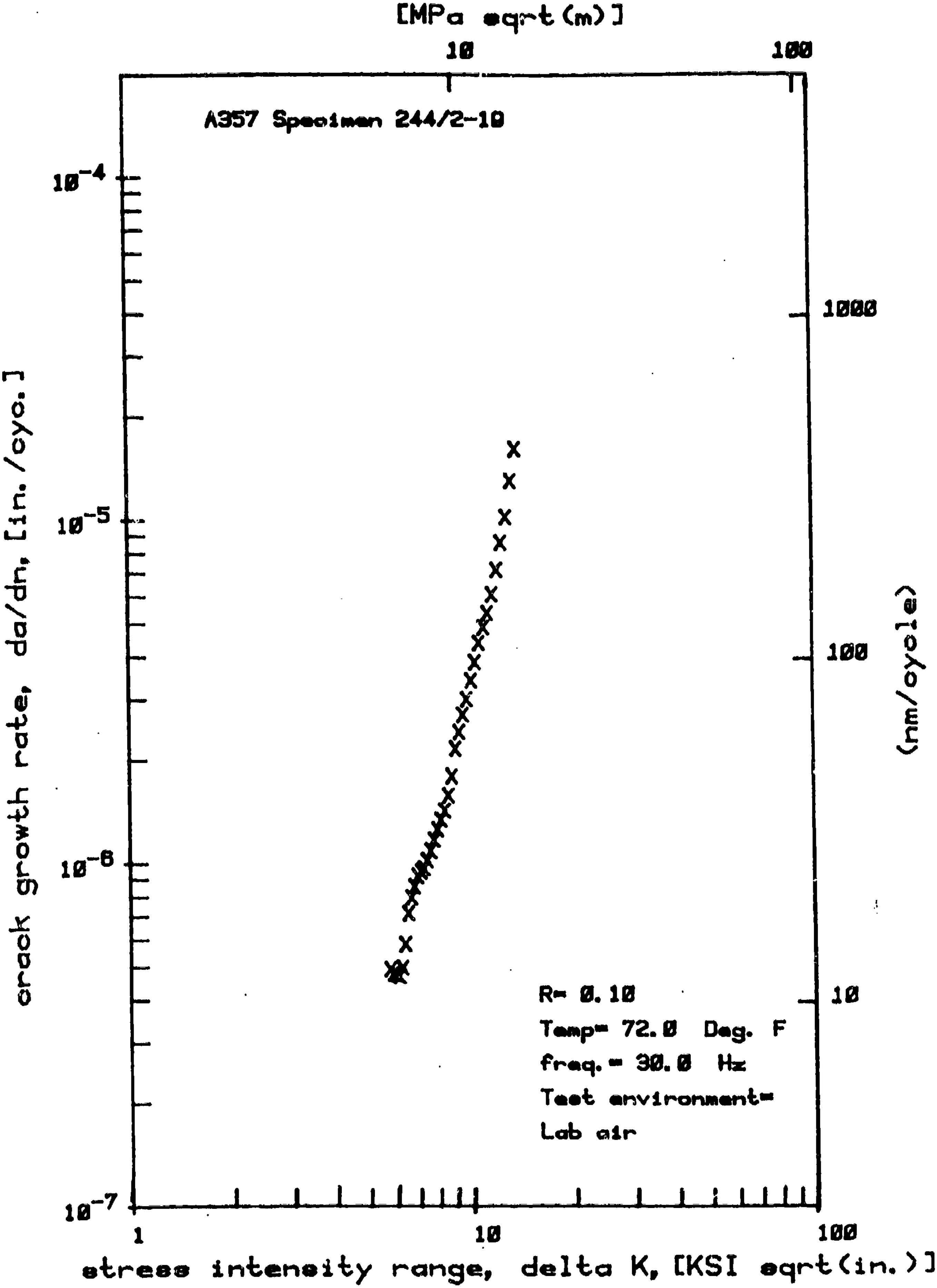

Figure 7. Fatigue crack growth plot of A357-T6 Specimen 244/2-19.

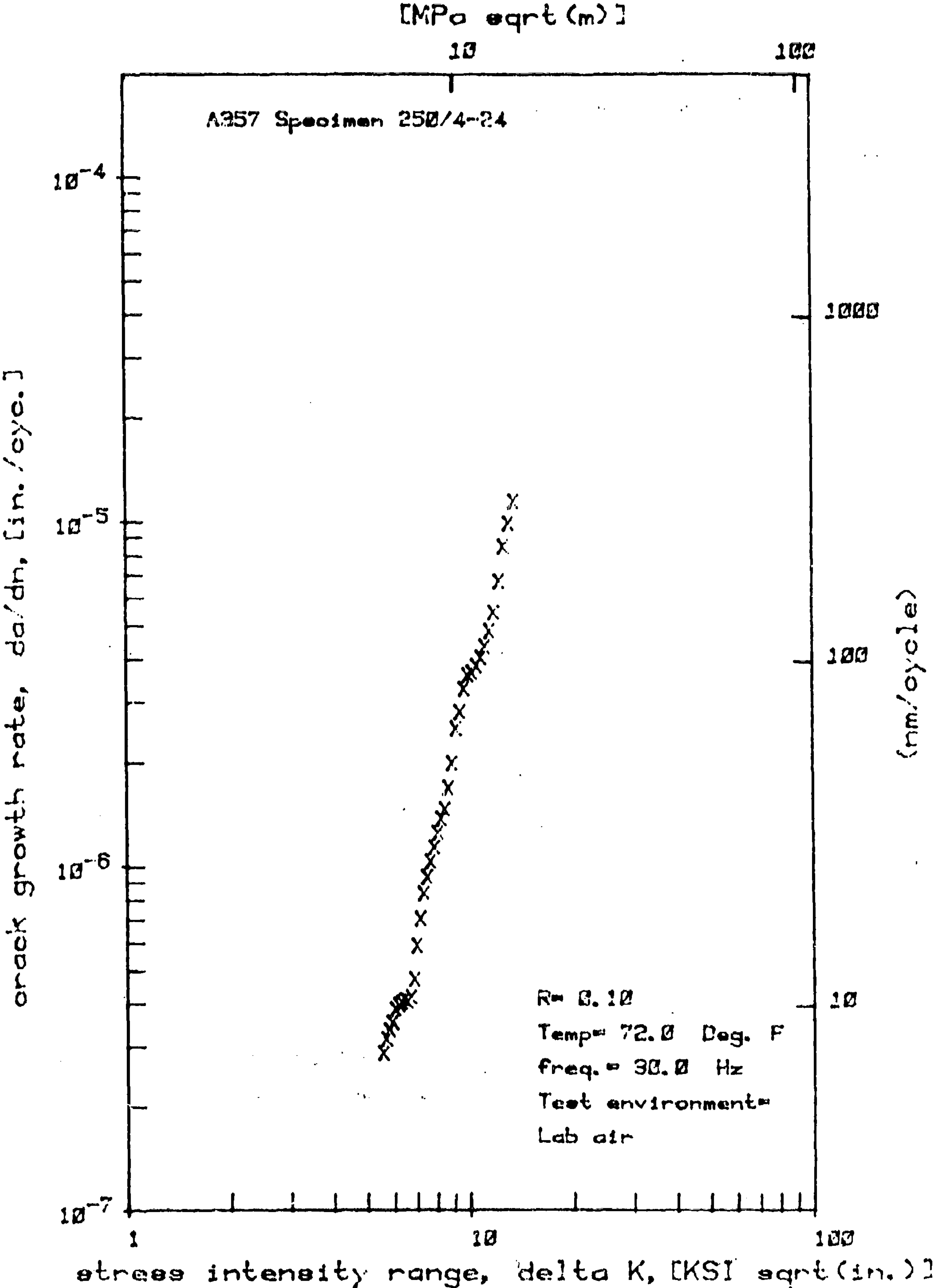

Figure 8. Fatigue crack growth plot of A357-T6 Specimen 250/4-24.

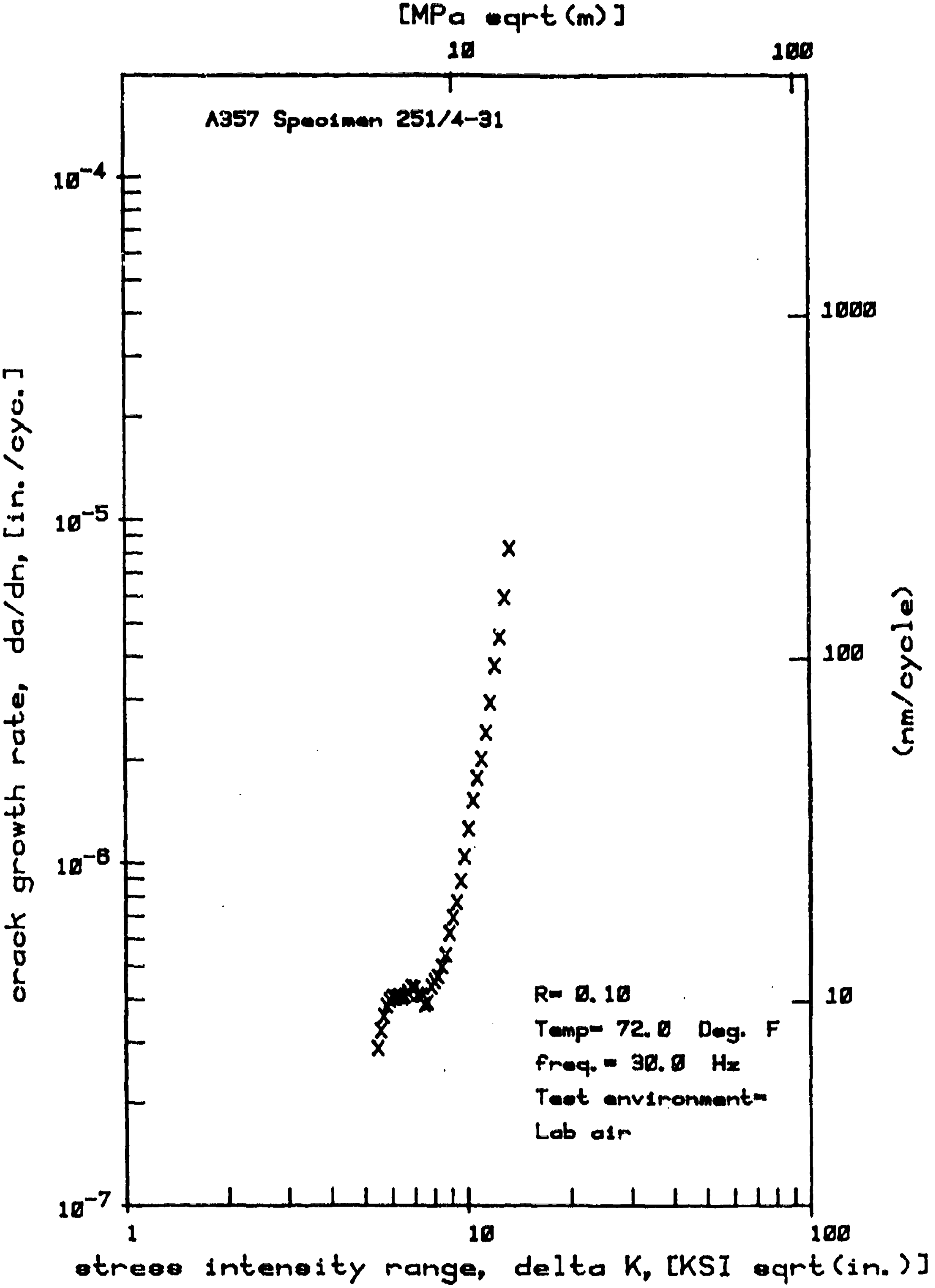

Figure 9. Fatigue crack growth plot of A357-T6 Specimen 251/4-31.

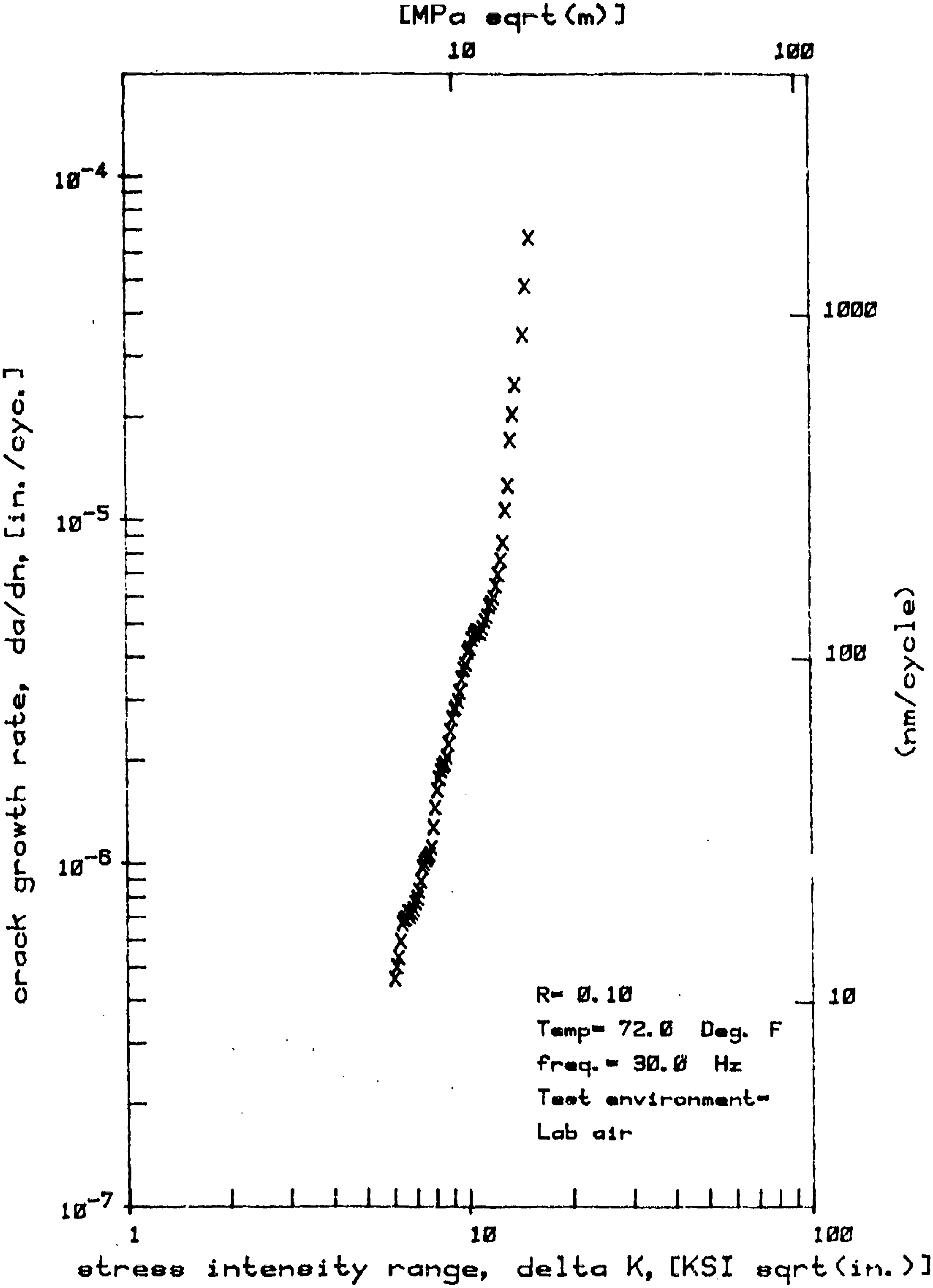

Figure 10. Specimen 89CG1 Low Si fatigue crack growth plot.

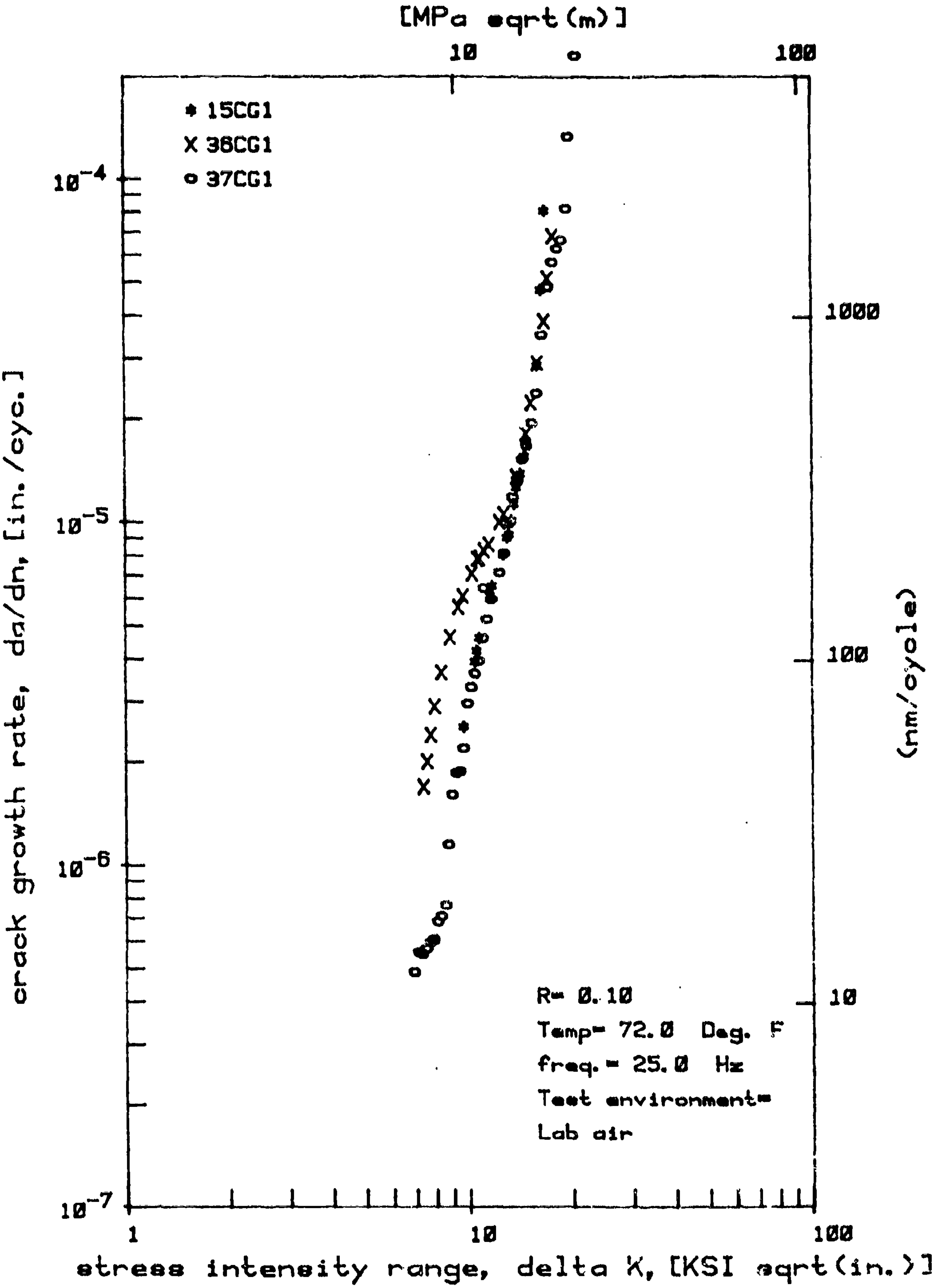

Figure 11. Combined plot specimens from Magnesium Alloy Co.

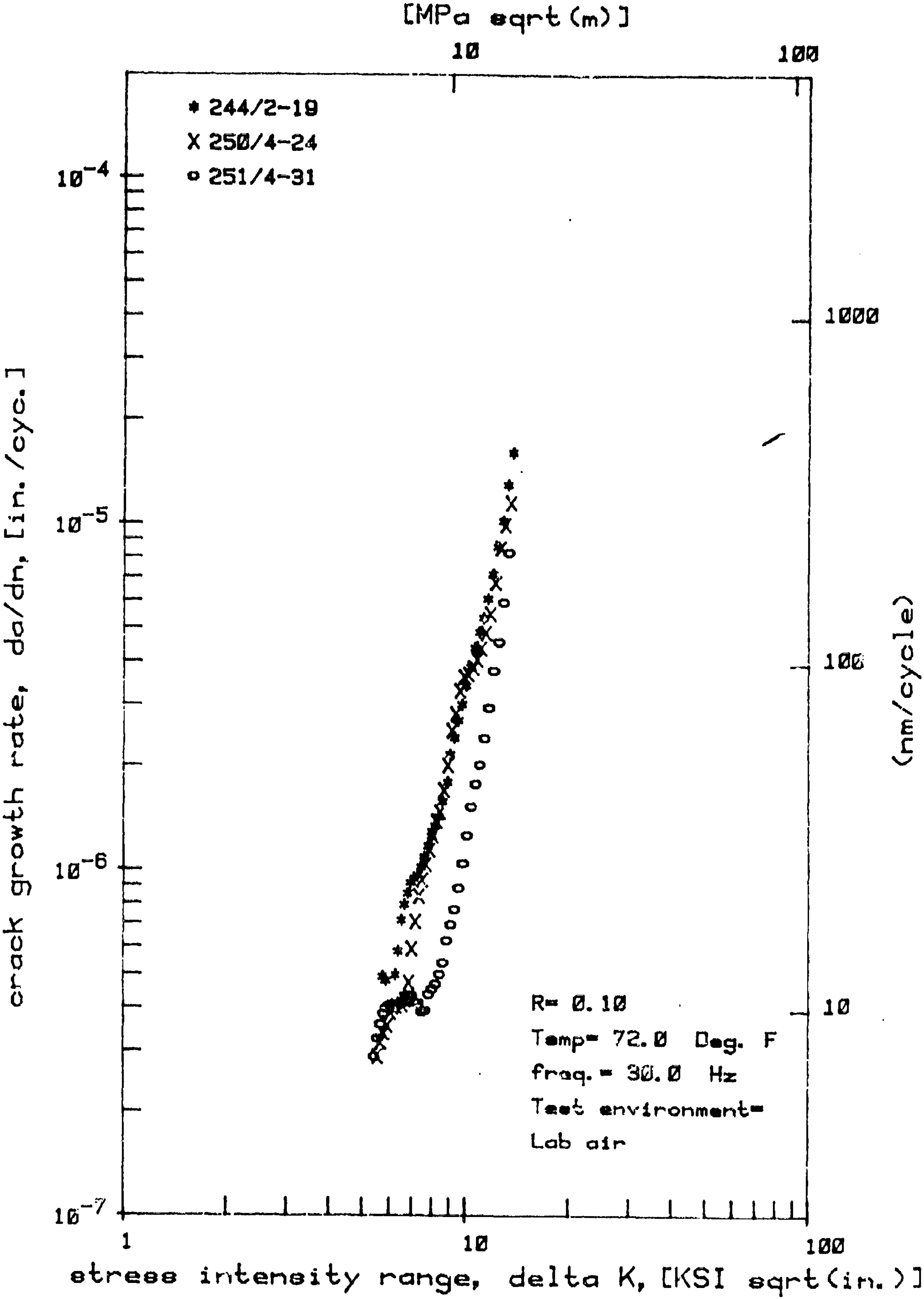

Figure 12. Combined plot specimens from Magnesium Alloy Co.

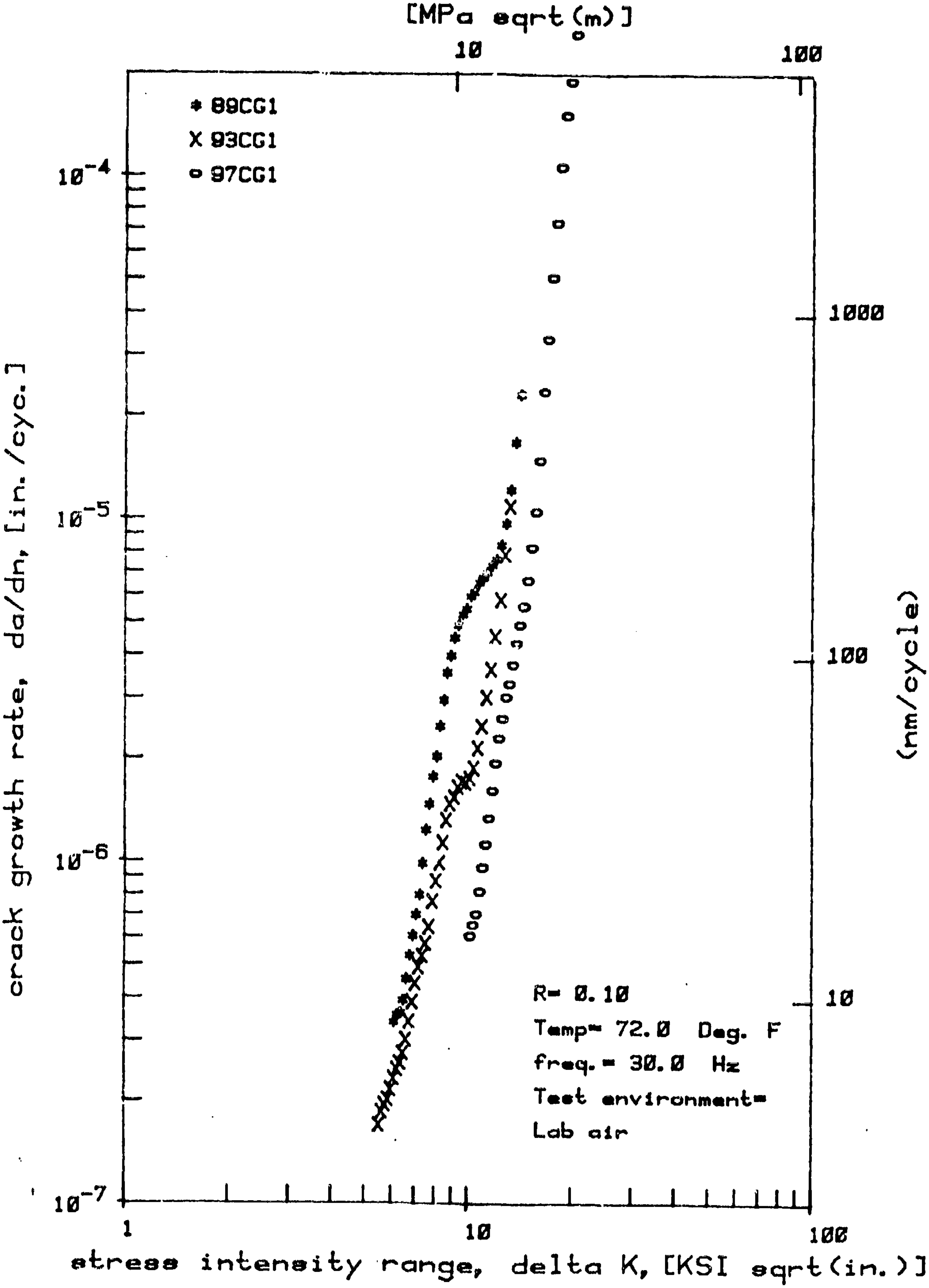

Figure 13. Combined plot of Teledyne specimens.

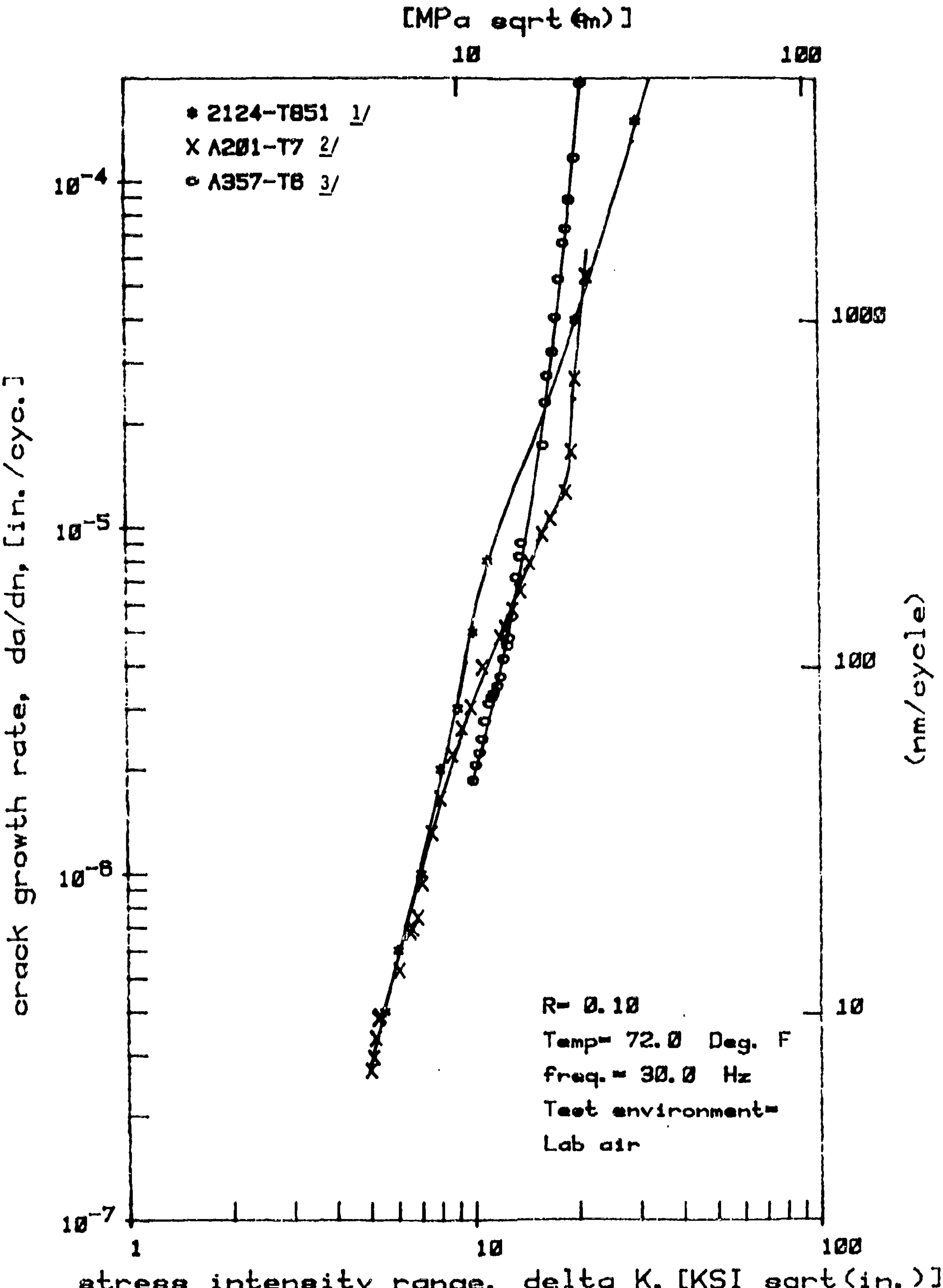

Figure 14. Comparison data plot.

REFERENCES

1/ Military Standardization Handbook 5D, Metallic Materials and Elements for Aerospace Vehicle Structures, p. 3 - 146.

2/ Fatigue Crack Growth Testing of Cast Aluminum Alloy A201-T7, J.D. Tirpak, MLS-83-88, p. 5.

3/ Cast Aluminum Structures Technology (CAST), Structural Test and Evaluation (Phase V), Part II - Fatigue and Fracture Properties of Cast Aluminum Bulkheads, C.K. Gunther, AFWAL-TR-80-3021, Part II, p. 42.

APPENDIX G

EVALUATION REPORT - FATIGUE CRACK GROWTH
TESTING OF CAST ALUMINUM ALLOY
A201-T7

SYSTEMS SUPPORT DIVISION
AFWAL MATERIALS LABORATORY
WRIGHT PATTERSON AIR FORCE BASE, OHIO

EVALUATION REPORT

FATIGUE CRACK GROWTH TESTING OF CAST ALUMINUM ALLOY A201-T7

REPORT NR: MLS-83-88

DATE: 9 NOV 83

PROJECT NR: 24180703

TYPE EVALUATION: Constant-Load-Amplitude Fatigue Crack Growth Tests

MANUFACTURER: N/A

SUBMITTED BY: Northrop Corporation
ATTN: Mr Kermit J. Cswalt
Metallic Materials Research
& Advanced Manufacturing
Technology
Orgn 3872/62, Aircraft Div
One Northrop Avenue
Hawthorne CA 90250

SPEC NR: N/A

SERIAL NR: N/A

WUD NR: N/A

I. PURPOSE:

To generate constant-load-amplitude fatigue crack growth data for cast aluminum A201-T7.

II. BACKGROUND:

A201 is a heat-treatable, aluminum-copper-silver casting alloy which possesses relatively high strength mechanical properties in the -T7 condition. Although A201 has been cast for several years in various configurations it still lacks a comprehensive statistically analyzed data base. Without this data, which includes damage tolerance critical data, A201 is generally specified only for structural and component applications that are not flight-critical. Both the aerospace industry and the Air Force are interested in the cost savings that can be realized through the wider use of castings and are working towards eliminating the data void.

As a major step in developing such data the Northrop Corporation under Air Force contract, is generating supplementary MIL-HDBK-5 data for cast A201 and A357. A part of this program involves obtaining A201 castings from several sources, expanding the existing data base and eventually deriving design allowables. To augment this effort the Systems Support Division (AFWAL/MLSE) agreed to conduct fatigue crack growth testing of A201 in exchange for A201 step plates. Additional in-house work is also planned to obtain elevated temperature data. This report describes, the fatigue crack growth testing performed and the results obtained for A201.

III. SPECIMENS:

Six A201-T7 fatigue crack growth specimens were supplied to the Systems Support Division by Northrop. The specimens were standard compact-type (CT) specimens, 0.368 inches thick (B) and 2.000 inches wide (W).

Alloy chemistry was within the following limits:

Copper	4.5 - 5.0 percent
Silver	0.5 - 1.0 percent
Manganese	0.20 - 0.50 percent
Magnesium	0.25 - 0.35 percent
Titanium	0.15 - 0.30 percent
Iron	0.05 percent max
Silicon	0.10 percent max
Aluminum	Balance

Ultimate strength, yield strength and fracture toughness values were estimated as 60 ksi, 55 ksi, and 30-33 ksi $\sqrt{\text{inch}}$ respectively.

IV. TEST PROCEDURES:

Tests were conducted in accordance with ASTM standard E 647, "Standard Method for Constant-Load-Amplitude Fatigue Crack Growth Rates Above 10^{-8}m/cycle."

Specimens were precracked and tested on a 25 kip electrohydraulic fatigue machine. Crack length was measured optically using a traveling microscope.

An R ratio of 0.1 was applied sinusoidally at 25 Hz.

All tests were conducted at room temperature in lab air.

V. RESULTS AND DISCUSSION:

Of the six specimens, one specimen failed during test set up. The other five specimens were tested without incident.

Using a seven point polynominal method, a desk top computer calculated and plotted the fatigue crack growth data in Figures 1 - 6. Figure 1 was constructed to show the combined data set. A comparison of the data in Figure 1 with similar data from MIL-HDBK-5D on 2124-T851 wrought plate 2 inch - 5 inch thick (specified 65 ksi ult) indicates that within the 10^{-6} to 10^{-5} inch/cycle range, both materials have similar crack growth rates. During testing it was noted that the fatigue crack followed a tortuous route and branched regularly. This contributes to the fatigue crack resistance of A201.

VI. CONCLUSIONS:

The data was submitted to Northrop Aircraft to augment and be included in their own A201 data development program. There was nothing in the AFWAL data that indicated any unusual concern with the crack growth characteristics of this cast alloy, and in fact it appeared competitive (from a crack growth standpoint) with commonly used wrought products.

Prepared by:

JON D. TIRPAK, 2LT, USAF

Coordination:

CLAYTON L. HARMSWORTH

PUBLICATION REVIEW

This report has been reviewed and is approved by:

THEODORE J. REINHART, Chief
Materials Engineering Branch
Systems Support Division

Distribution:

AFWAL/TSTM
AFWAL/MLS
AFWAL/MLSE (Reinhart)
AFWAL/MLSA (Cooper)
AFWAL/MLSS (Maj Hardy)
Northrop Corp. (Kermit Oswalt)
Northrop Corp. (Yuli Lii)

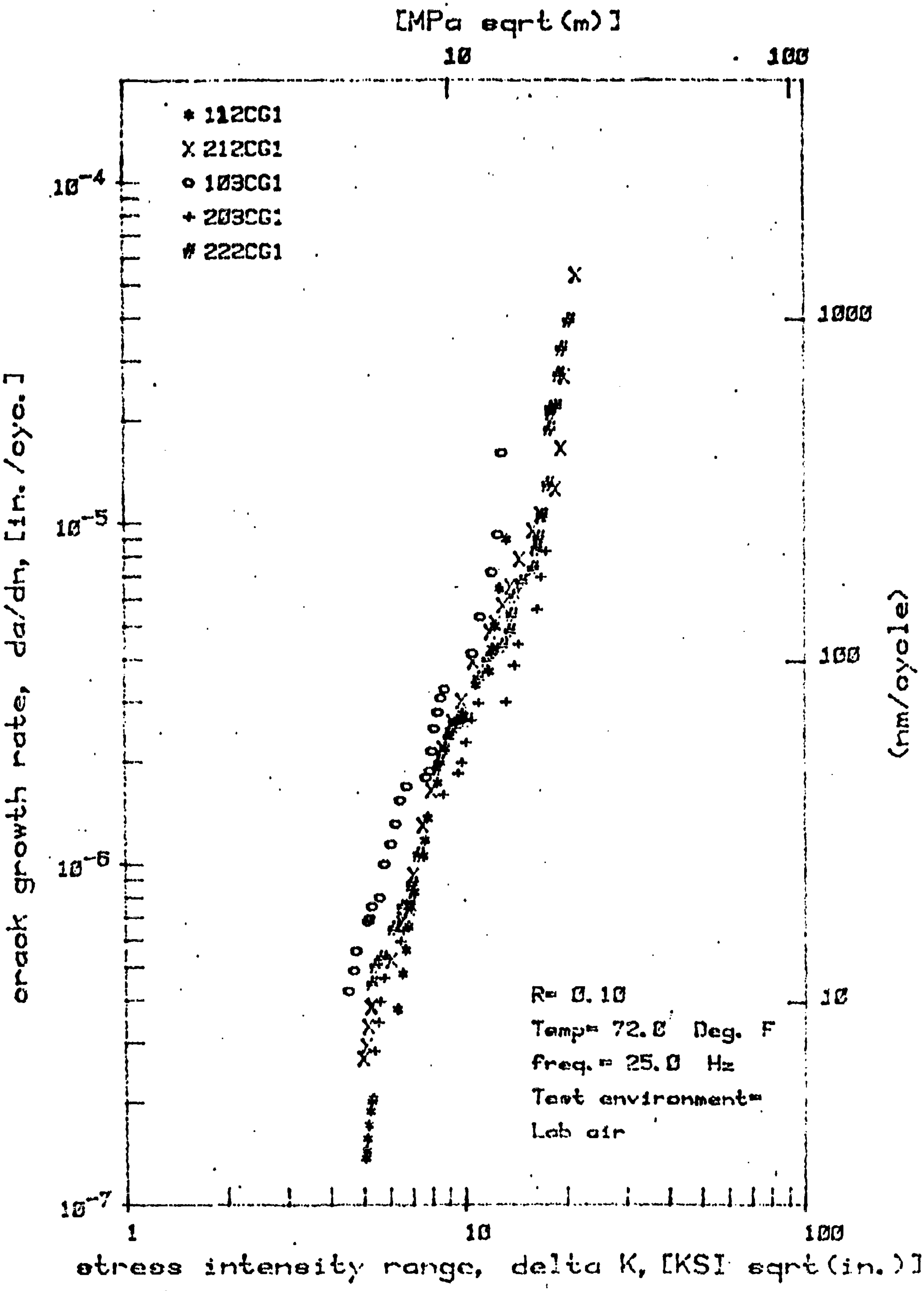

Figure 1: Combined plot of fatigue crack growth data for A201 specimens.

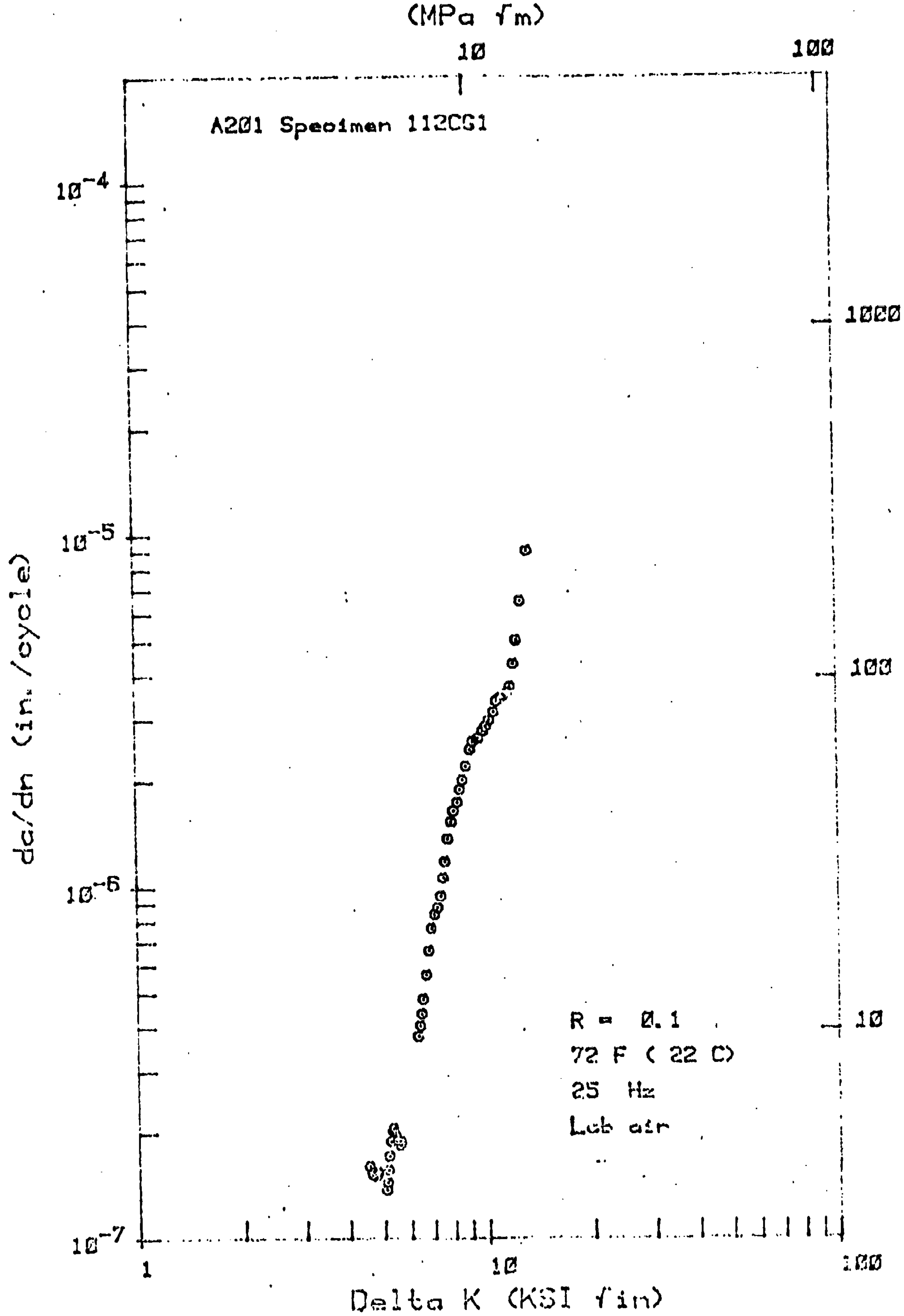

Figure 2: Fatigue crack growth rate plot for specimen 112CG1.

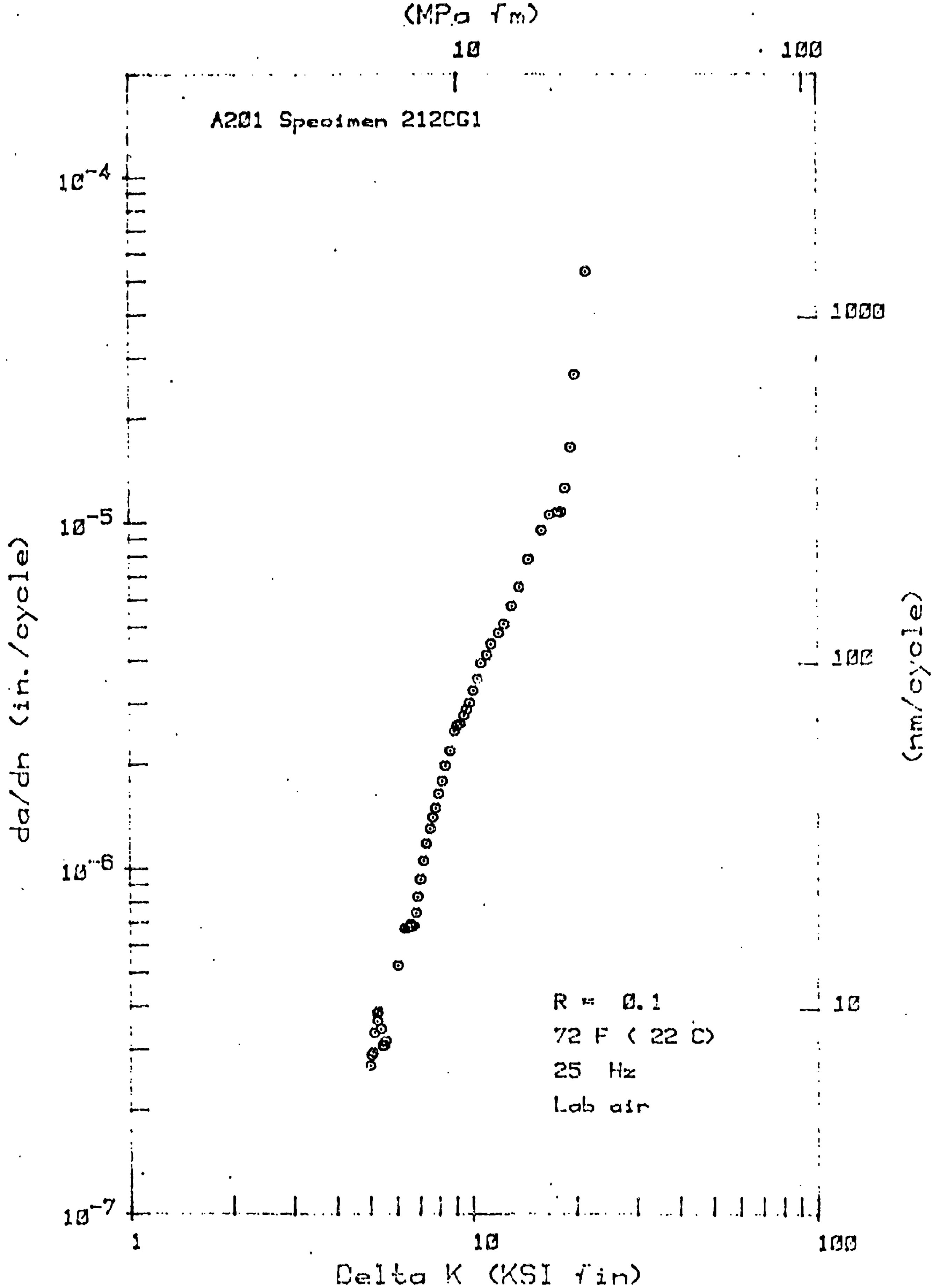

Figure 3: Crack growth rate plot for specimen 212CG1.

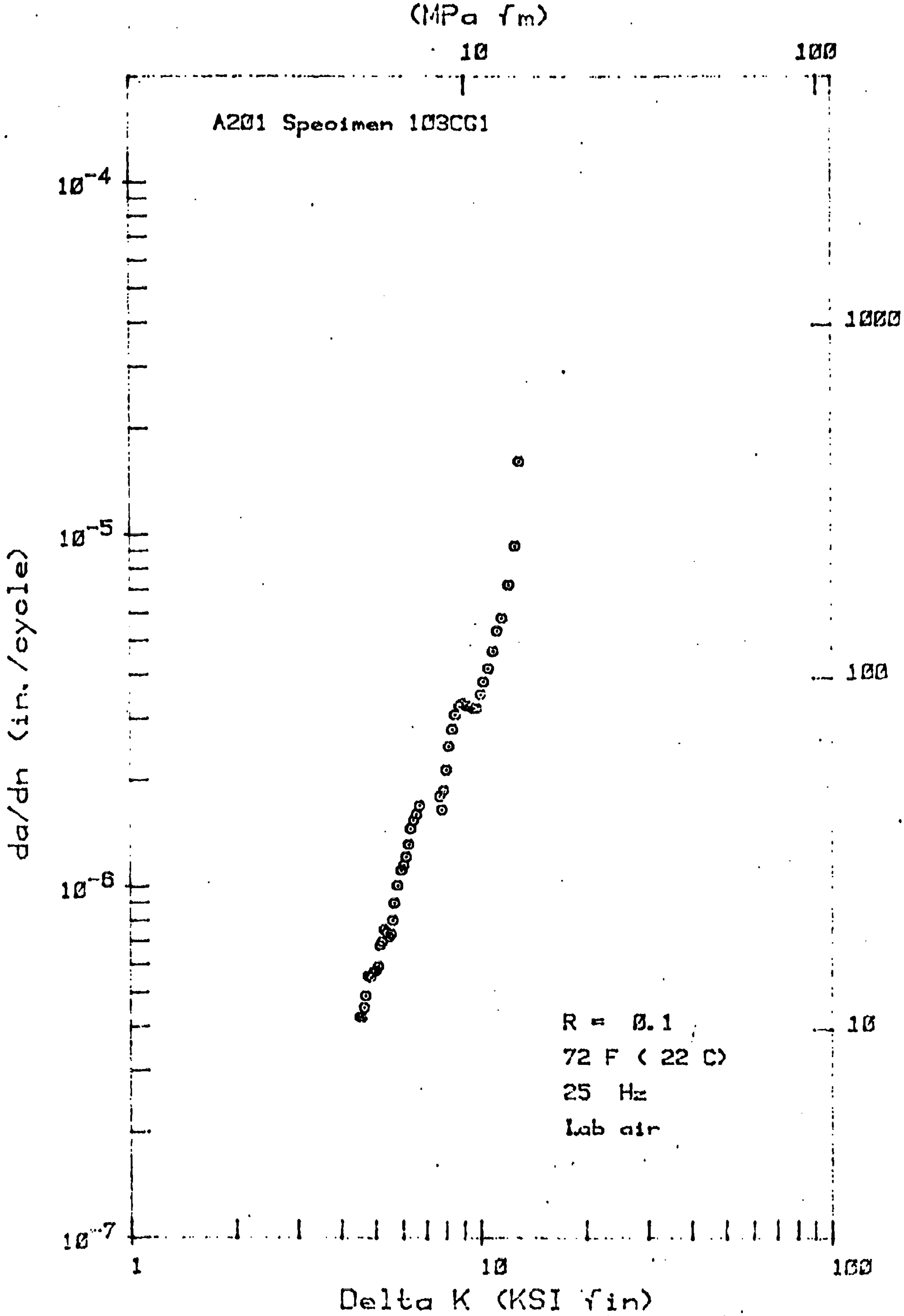

Figure 4: Fatigue crack growth rate plot for specimen 103CG1

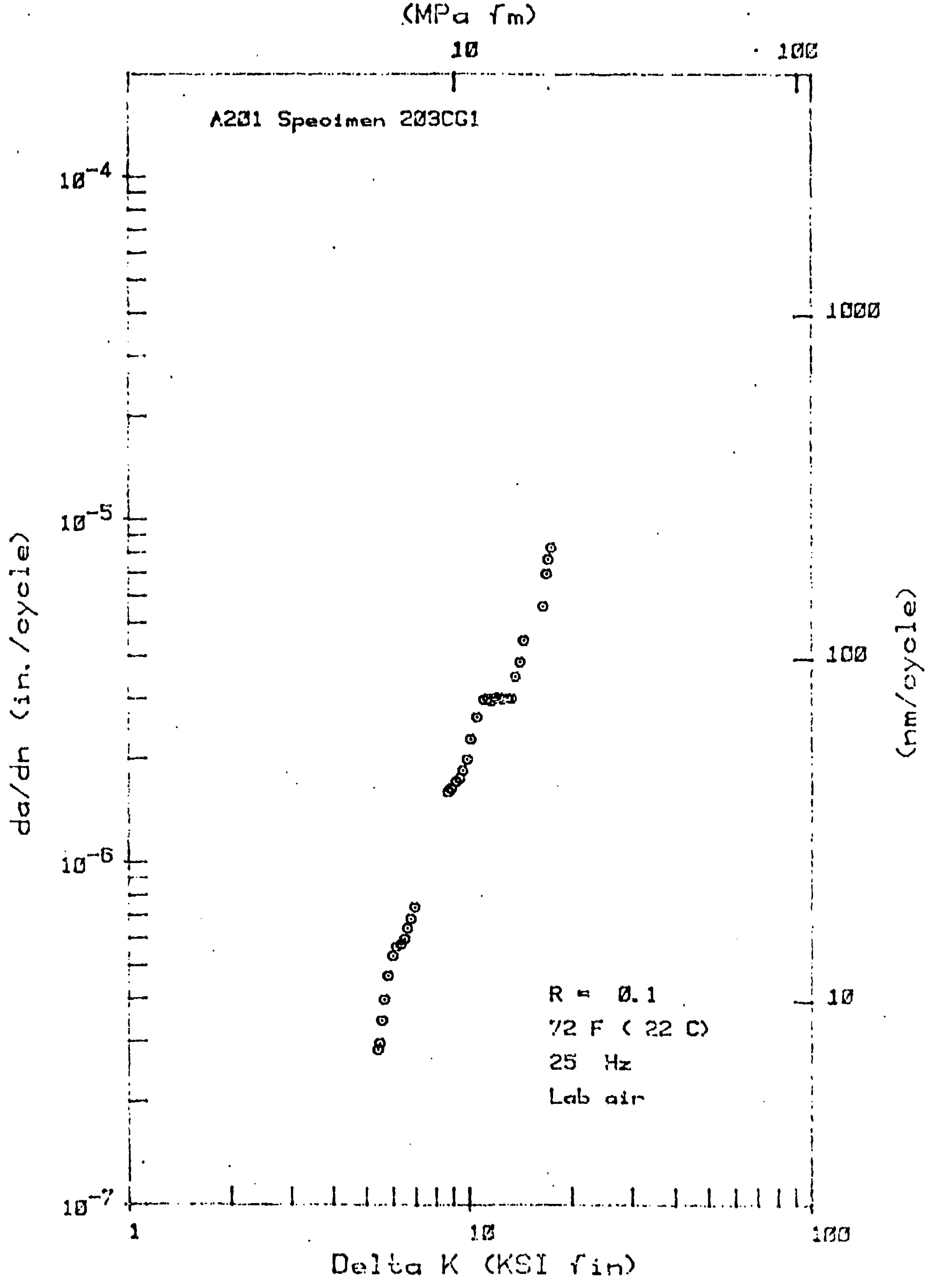

Figure 5: Fatigue crack growth rate plot for specimen 203CG1.

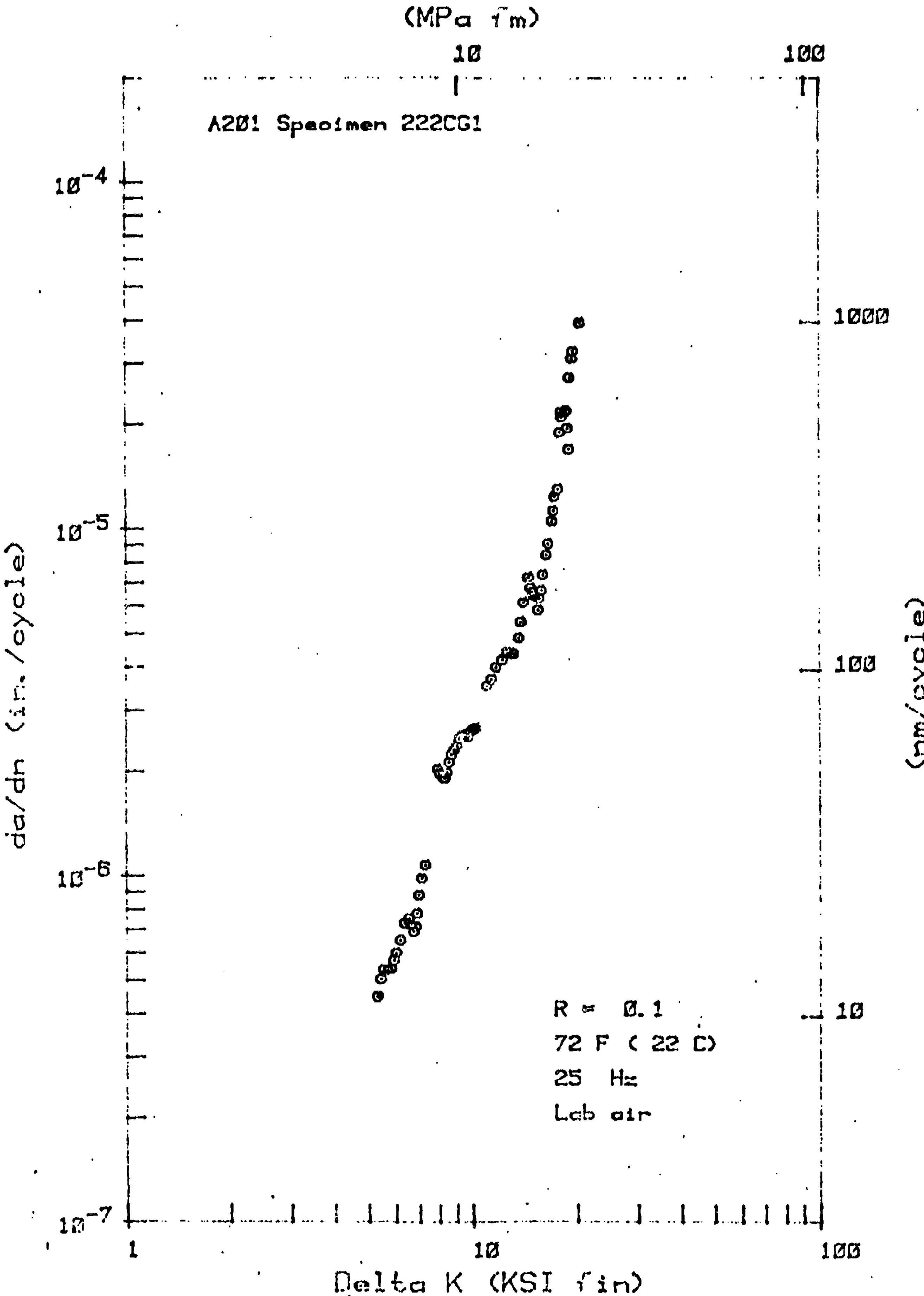

Figure 6: Fatigue crack growth rate plot for specimen 222CG1.

APPENDIX H

SPECIFICATIONS

NORTHROP

N3882-84-38
JGL:KW:mlh

23 May 1984

Ms. Meg Steigerwald
SAE Aerospace AMS Coordinator
400 Commonwealth Drive
Warrendale, PA 15096

Subject: THREE NEW PROPOSED AMS ALUMINUM CASTING SPECIFICATIONS

Dear Ms. Steigerwald:

The attached proposed specifications are submitted for your consideration as AMS specifications. The proposed specifications and the AMS draft numbers acquired from you are as follows:

AMS Draft 40GC	Aluminum Alloy Castings, Sand Composite Structural Aircraft Quality 7.0Si - 0.60Mg (A357-T6) Solution and Precipitation Heat Treated
AMS Draft 40GD	Aluminum Alloy Castings, Sand Composite Structural Aircraft Quality 4.7Cu - 0.75Ag - 0.35Mn - 0.30Mg -0.22Ti (A201.0 - T7) Solution Treated and Overaged
AMS Draft 40GE	Determination and Acceptance of Dendrite Arm Spacing in Aluminum Castings

These specifications have been reviewed and approved by an Ad Hoc casting group of the MIL-HDBK-5 Committee which consisted of aircraft industry materials engineers, foundry industry metallurgical engineers, and chaired by Mr. Paul E. Ruff of Battelle (and also a member of AMD).

A need was recognized by the Air Force for cast structures in aircraft that exhibit optimum properties and reliability. Such castings offer significant cost savings if specifications are available which will provide the necessary casting integrity permitting the elimination of casting factors in design. The proposed quality assurance provisions of these specifications are unique in the metals industry. Anticipated users of these materials are all the airframe manufacturers. The airframe manufacturers who were represented in the Ad Hoc Review Group

Northrop Avenue, Hawthorne, California 90250 • Telephone (213) 970-2000

Mrs. Meg Steigerwald
23 May 1984

N3382-84-38
Page 2

supporting the need and issuance of AMS coverage included McDonnell Douglas-Long Beach, General Dynamics-Forth Worth, Lockheed-Burbank, and Northrop. A final report which documents the four-year effort to develop these specifications, including the statistical developed property requirements, is scheduled to be released later this year by the Air Force.

It is recognized that there are existing AMS specifications for A357-T6 and A201-T7 cast materials. However the proposed specifications, which contain more stringent controls, were developed specifically for aircraft structural applications. For this reason, it was not recommended to modify or replace the existing specifications.

I offer to sponsor these specifications through the circulation and approval procedure. Mr. Jean G. Louvier, Chairman of Commodity D (Non-Ferrous Alloys) of AMD and an associate of mine at Northrop, has offered to assist me in this effort.

It is hoped that these specifications can be circulated for review and comment in time to be on the agenda of the October 8 AMD meeting in Portland, Maine.

If there are any questions regarding this matter, please contact the undersigned.

NORTHROP CORPORATION
Aircraft Division

Kermit J. Oswalt
Metallic Materials and
Processes Applications
Dept. 3882/62
Telephone: (213) 970-4963

Attachments: (3)

P.S. - To clarify the need and use of these proposed specifications, it is requested that this letter be distributed along with the specifications.

Ms. Meg Steigerwald
Proposed AMS Draft 40GC by Kermit Oswalt
Northrop Corporation
(213) 970-4963
23 May 1984

ALUMINUM ALLOY CASTINGS, SAND COMPOSITE
7.0Si - 0.60Mg (A357.0 - T6)
Solution and Precipitation Heat Treated
Structural Aircraft Quality

1. SCOPE

1.1 Form: This specification covers an aluminum alloy in the form of sand composite molded castings.

1.2 Application: Primarily for structural aircraft components.

1.3 Preproduction Qualification: The foundry supplying castings to this specification must have the preproduction approval of the purchaser in accordance with 4.4.

2. APPLICABLE DOCUMENTS: The following publications form a part of this specification to the extent specified herein. The latest of Aerospace Material Specifications (AMS) shall apply. The applicable issue of other documents shall be as specified in AMS 2350.

2.1 SAE Publications: Available from Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096.

2.1.1 Aerospace Material Specifications:

AMS 2350 - Standards and Test Methods
AMS 2360 - Room Temperature Tensile Properties of Castings
AMS 2804 - Identification Castings
AMS XXXX - Determination of Dendrite Arm Spacings in Aluminum Castings
AMS 2694 - Repair Welding of Aerospace Castings

2.2 ASTM Publications: Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASTM B557 - Tension Testing of Wrought and Cast Aluminum and Magnesium Alloy Products
ASTM E18 - Test for Rockwell Hardness and Rockwell Superficial Hardness Metallic Materials
ASTM E34 - Chemical Analysis of Aluminum and Aluminum Alloys
ASTM E155 - Reference Radiographs for Inspection of Aluminum and Magnesium Castings, Series III

2.3 Government Publications: Available from Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.

2.3.1 Federal Standards:

Federal Test Method Standard No. 151 - Metals; Test Methods

2.3.2 Military Specifications:

MIL-H-6088 - Heat Treatment of Aluminum Alloys
MIL-I-6866 - Inspection, Penetrant Method of
MIL-I-25135 - Inspection Materials, Penetrant

2.3.3 Military Standards:

MIL-STD-410 - Qualification of Inspection Personnel
MIL-STD-649 - Aluminum and Magnesium Products, Preparation for Shipment and Storage

MIL-STD-00453 - Military Standard Inspection, Radiographic

2.3.4 Industry Standards:

NAS 823 Cast Surface Comparison Standard

3. TECHNICAL REQUIREMENTS

3.1 Composition: Shall conform to the following percentages by weight, determined by wet chemical methods in accordance with ASTM E34, by spectrographic methods in accordance with Federal Test Method Standard No. 151, Method 112, or by other approved analytical methods:

	Foundry Melt Analysis		Tolerance for Casting Analysis	
	min.	max.	Below min.	Above max.
Silicon	6.5	7.5	0.5	0.5
Magnesium	0.55	0.65	0.05	0.05
Titanium	0.10	0.20	-	-
Beryllium	0.04	0.07	-	-
Iron	-	0.20	-	-
Manganese	-	0.35	-	-
Other Impurities, each	-	0.05	-	-
Other Impurities, total	-	0.15	-	-
Aluminum	remainder		remainder	

3.2 Condition: Solution and precipitation heat treated.

3.3 Casting: Castings shall be produced from metal conforming to 3.1. The chemical sample taken from the molten bath of the melt shall conform to the foundry melt analysis requirements. The casting analysis tolerance requirements shall apply only to samples taken from a casting.

3.3.1 A melt shall be a single homogenous batch of molten metal to which all processing has been completed and the temperature has been adjusted ready for pouring castings.

3.3.2 A lot of castings shall be all castings poured from a single melt in not more than eight consecutive hours and solution and precipitation heat treated in the same heat treatment batch.

3.3.3 Each casting shall be identified by a individual serial number to relate processing of the part with the inspection results for traceability.

3.4 Chemical Analysis Specimens: Shall be cast from each melt.

3.5 Integrally Attached Coupons: A minimum of two coupons shall be integrally attached to each casting. These coupons shall be used for tensile property determination specified in 3.7.1.1 and microstructure evaluation specified in 3.8.3. Others may be added for retest and foundry purposes at the option of the foundry.

3.5.1 Location and size of the integrally attached coupons are optional with the following exceptions:

3.5.1.1 The coupons must be flat and at least large enough to permit excision of a sub-size round tensile specimen of 0.250 inch diameter per ASTM B557 with a minimum gage length of one inch.

3.5.1.2 The coupons must be located in such a manner to avoid any interference with inspection tooling.

3.5.2 The two coupons shall be produced in such a manner to develop a relative fine microstructure in one coupon compared to the other coupon which shall be produced with a relative coarse microstructure. A minimum size difference of 0.0010 inch in the average dendrite arm spacing (DAS) is desired.

3.5.3 The radiographic quality of the coupons shall meet the requirements for designated areas of Table 1.

3.5.4 The removal and testing of integrally attached coupons for casting acceptance shall be performed by a testing facility which has been approved by the purchaser.

3.6 Heat Treatment: Castings and integrally attached test coupons shall be solution and precipitation heat treated in accordance with MIL-H-6088 except as otherwise specified herein.

3.6.1 The solution heat treat temperature shall be 1000 to 1020F (538-549C).

3.6.2 The quenching and aging procedure shall be established to develop the required casting properties.

3.7 Properties: Castings and integrally attached chilled test coupon shall conform to the following requirements:

3.7.1 Tensile Properties: Shall be as follows, determined in accordance with ASTM B557 and shall be used as basis for acceptance of castings.

3.7.1.1 Integrally Attached Chilled Test Coupon: For heat treat control, the following tensile properties shall be exhibited:

Tensile Strength, min. 52 ksi
Yield Strength at 0.2% Offset, Range 42 to 47 ksi

3.7.1.2 Specimens Cut from Castings: Tensile properties of specimens cut from the casting shall be as follows:

3.7.1.2.1 Designated Casting Areas:

Tensile Strength, min. 50,000 psi
Yield Strength at 0.2% Offset, min. 40,000 psi
Elongation, min. 3%

3.7.1.2.2 Casting areas other than designated areas:

Tensile Strength, min. 45,000 psi
Yield Strength at 0.2% Offset, min. 36,000 psi
Elongation, min. 2%

3.7.1.2.3 When properties other than those of 3.7.1.2.1 or 3.7.1.2.2 are required, tensile test specimens taken from locations indicated on the drawing, from a casting chosen at random to represent the lot, shall have the properties indicated on the drawing for such specimens. Property requirements may be designated in accordance with AMS 2360.

3.7.1.2.4 Excised specimens shall be subsize and proportional to the standard round or sheet type specimens defined in ASTM B557.

3.8.2 Hardness of Castings: Castings, should have hardness of HRE 90 minimum determined in accordance with ASTM E18, but castings shall not be rejected only on the basis of hardness.

3.8.3 Microstructure: The surface microstructure shall be evaluated as an added means of quality assurance only. Castings which exhibit an unacceptable microstructure, shall be held for disposition by the cognizant engineering procurement personnel.

3.8.3.1 The microstructure of the casting surface in the designated areas of the casting shall not exceed the maximum size coarseness determined in accordance with specification AMS-XXXX.

3.9 Quality

3.9.1 Castings as received by purchaser, shall be uniform in quality and condition, sound, and free from foreign materials and from internal and external imperfections detrimental to usage of the castings.

3.9.1.1 Castings shall have a surface finish in accordance with the engineering drawing and NAS 823 and shall be well cleaned.

3.9.2 Castings shall be produced under foundry control. This control shall consist of pre-production examination of castings until proper foundry technique and controls are established which will produce castings that will meet the drawing quality and dimensional requirements.

3.9.3 Radiographic inspection shall be performed in accordance with MIL-STD-00453. In addition, Type 1 radiographic film shall be used, and a maximum unsharpness value of 0.003 inch (0.08 mm) and flaw sensitivity of 1% shall be maintained. ASTM E155 shall be used to define radiographic acceptance standards in accordance with Table 1.

3.9.4 Castings shall be subjected to fluorescent penetrant inspection in accordance with MIL-I-6866.

3.9.4.1 The fluorescent penetrant shall have a sensitivity level equivalent to group V of MIL-I-25135.

3.9.4.2 Personnel conducting the testing shall be qualified and certified in accordance with the requirements of MIL-STD-410.

3.9.4.3 Linear indications, cold shuts, cracks, and seams are cause for rejection.

3.9.4.4 Surface porosity is cause for rejection if the individual pores are closer than twice their maximum dimension to an edge or extremity of the casting or the pores form a linear indication, i.e., three or more are in a line and the distance between each indication is less than twice the maximum dimension of either adjacent indication.

3.9.4.5 Any individual indication which is three times longer than it is wide shall be considered a linear indication and shall be cause for rejection.

3.9.5 Castings shall not be repaired by peening, plugging, welding, or other methods, except as defined in 3.9.5.1.

3.9.5.1 Defects in non-critical areas of the casting may be removed and the castings repaired by welding in accordance with AMS 2694 and using A357 alloy filler metal. Repair welding shall be performed prior to any heat treatment and final nondestructive testing specified herein.

3.10 Marking

3.10.1 Each casting shall be identified by legible raised figures with part number, foundry identification, and serial number in the area indicated on the engineering drawing. The serial number shall be used only once to provide traceability to the processing of a particular part.

3.10.2 Each casting accepted by radiographic inspection shall be ink stamped in accordance with MIL-STD-00453.

3.10.3 Each casting accepted by penetrant inspection shall be ink stamped in accordance with MIL-I-6866.

3.10.4 Integrally attached test coupons or prolongations shall be identified by a vibroetched serial number corresponding with the casting serial number.

3.10.5 Castings and the accompanying reports shall identify the heat treatment and melt analysis of each casting through the serial number.

3.10.6 When impregnation is specified or permitted by purchaser, castings shall be marked IMP.

4. QUALITY ASSURANCE PROVISIONS:

4.1 Responsibility for Inspection: The vendor of castings shall be responsible for coordinating all acceptance testing of production castings at the purchaser's approved facilities. The tensile testing of specimens excised periodically from castings and DAS determinations when required shall be performed at an approved testing facility that is independent of the foundry. Results of such test shall be reported to the purchaser as required by 4.5. Purchaser reserves the right to perform such confirmatory testing as he deems necessary to ensure that the castings conform to the requirements of this specification.

4.2 Classification of Tests:

4.2.1 Acceptance Tests: Tests to determine conformance to requirements for composition (3.1), tensile properties of integrally attached test coupons (3.7.1.1), tensile properties of specimens cut from castings (3.7.1.2) and quality (3.9) are classified as acceptance tests and shall be performed on each casting, melt, or lot as applicable.

4.2.2 Periodic Tests: Tests to determine conformance to requirements for hardness (3.8.2) and microstructure (3.8.3), are classified as periodic tests and shall be performed at a frequency selected by the vendor unless frequency of testing is specified by purchaser.

4.2.3 Preproduction Tests: Tests to determine conformance to all technical requirements of this specification are classified as preproduction tests and shall be performed on the first-article shipment of castings to a purchaser, when a change in material or processing requires reapproval, as in 4.4, and when purchaser deems confirmatory testing is required.

4.2.3.1 For direct U.S. Military procurement, substantiating test data and, when requested, preproduction test material shall be submitted to the cognizant agency as directed by the procuring activity, the contracting officer, or the request for procurement.

4.3 Sampling: Shall be in accordance with the following:

4.3.1 One chemical analysis from each melt or one chemical analysis from each of two castings in each lot.

4.3.2 Each casting shall be radiographically and fluorescent penetrant inspected.

4.3.3 When required, specific test sites on the casting and frequency of evaluating castings for surface microstructure shall be defined by the purchaser at the time of preproduction approval.

4.3.4.1 First 30 Castings Received: One casting of each 10 shall be selected for destructive testing.

4.3.4.2 Castings Received Thereafter: If no failure occurs in 4.3.4.1, one casting in each 25 consectively received there after shall be tested. If a failure occurs, the test frequency reverts to one in each 10 for the next 30 castings received.

4.3.4.3 The tensile properties of an integrally attached test coupon from each casting shall be determined. Removal of the attached coupon shall only be performed by an approved test facility that is independent of the foundry.

4.4 Preproduction Approval:

4.4.1 Sample castings from new or reworked patterns shall be approved by purchaser before production castings are supplied.

4.4.1.1 Two preproduction castings shall be furnished to the purchaser of each part number. One casting shall have been dimensionally inspected by the vendor and the results shall be forwarded with the casting for approval. The second casting shall be supplied to the purchaser for metallurgical evaluation in accordance with 4.2.3. All the vendor results obtained to substantiate the metallurgical quality of the casting shall be included.

4.4.2 Vendor shall document the parameters for the control factors of processing which will produce acceptable castings; for approval of sample castings of each part number. These shall constitute the approved casting procedure and shall be used for producing production castings. If necessary to make any change in parameters for the control factors of processing, vendor shall submit for reapproval a statement of the proposed changes in processing and, when requested, sample test specimens, castings, or both. Production castings incorporating the revised operations shall not be shipped prior to receipt of written reapproval.

4.4.2.1 Control factors for producing castings include, but are not limited to the following:

Melting practice regarding control of:

Chemistry
Gas content
Melt temperature

Molding procedure regarding:

Materials and assembly
Gating and risering systems
Solidification rate in designated areas

Heat treatment practice regarding:

Temperature and time parameters
Load density
Quenching procedure

Shop traveler describing the sequence of processing, inspection, and testing.

4.4.2.1.1 Any of the above control factors of processing for which parameters are considered proprietary by the vendor may be assigned a code designation. Each variation in such parameters shall be assigned a modified code designation.

4.5 Reports:

4.5.1 The vendor of castings shall furnish with each shipment three copies of a report showing the results of tests for chemical composition from each melt, tensile properties of attached specimens representing each casting and specimens cut from castings if applicable, penetrant and radiographic inspections of each casting by serial number, and when required, microstructure and hardness test results from each lot. This report shall include the purchase order number, material specification number and its revision letter, part number, and quantity.

4.5.2 The vendor of finished or semi-finished parts shall furnish with each shipment three copies of a report showing the purchase order number, material specification number and its revision letter, contractor or other direct supplier of castings, part number, and quantity. When castings for making parts are purchased by the parts vendor, that vendor shall inspect each lot of castings to determine conformance to the requirements of this specification, and shall include in the report a statement that the castings conform, or shall include copies of laboratory reports showing the results of tests to determine conformance. Castings produced by the parts vendor must be inspected in accordance with 4.2.

4.6 Resampling and Retesting:

4.6.1 Attached coupons

4.6.1.1 Retesting of the integrally attached coupon is permitted when an isolated flaw is evident on the fracture face of the broken tensile specimen.

4.6.1.2 Testing is required of an integrally attached chilled test coupon after reheat treatment. The replacement specimen shall be taken from an additional coupon which has remained integrally attached to the casting through the reheat treat process.

4.6.2 Tensile specimens excised from the casting.

4.6.2.1 Replacement of tensile specimens shall be allowed in accordance with ASTM E8 for poor machining, incorrect test procedure, malfunction of test equipment or fracture location.

4.6.2.2 Retesting of a tensile specimen excised from the castings is only permitted when the fracture face indicates an isolated gas hole, or piece of foreign material. Retesting shall be permitted by testing two adjacent specimens. Should it not be possible to obtain adjacent specimens, or if a replacement specimen also fails, then two additional castings shall be tested. The failure of a tensile specimen in a second casting shall be cause to consider the lot of castings suspect and the purchaser contacted for material review action. All castings shipped and in process since the last acceptable tensile test casting shall be reviewed for disposition.

4.6.2.3 All retest tensile specimens shall be located to represent as nearly as possible the quality of the metal of the original test. Isolated gas holes or foreign material that are discernable by production radiography may be avoided.

5. PREPARATION FOR DELIVERY

5.1 Identification: Castings shall be identified in accordance with AMS 2804.

5.2 Packaging:

5.2.1 Castings shall be prepared for shipment in accordance with commercial practice and in compliance with applicable rules and regulations pertaining to the handling, packaging, and transportation of the castings to ensure carrier acceptance and safe delivery. Packaging shall conform to carrier rules and regulations applicable to the mode of transportation.

5.2.2 For direct U.S. Military procurement, packaging shall be in accordance with MIL-STD-649, Level A or Level C, as specified in the request for procurement. Commercial packaging as in 5.1.1 will be acceptable if it meets the requirements of Level C.

6. ACKNOWLEDGMENT: A vendor shall mention this specification number and its revision letter in all quotations and when acknowledging purchase orders.

7. REJECTIONS: Castings not conforming to this specification or to authorized modifications will be subject to rejection.

8. NOTES:

8.1 Dimensions and properties in inch/pound units are primary; dimensions and properties in SI units are shown as the approximate equivalents of the inch/pound units and are not to be construed as standard for castings produced to SI dimensions.

TABLE I.

Maximum acceptance defects in aluminum alloy castings (maximum permissible radiograph in accordance with ASTM E155)

Defects	Radiograph reference	Designated Areas	Other Areas
Gas holes	1.1	1	2
Gas porosity (round)	1.21	1	3
Gas porosity (elongated)	1.22	1	3
Shrinkage cavity	2.1	1	2
Shrinkage porosity or sponge	2.2	1	2
Foreign material (less dense)	3.11	1	2
Foreign material (more dense)	3.12	1	2
Segregation	...	none	none
Cracks	...	none	none
Cold shuts	...	none	none
Laps	...	none	none

NOTES:

(1) When two or more types of defects are present to an extent equal to or not significantly better than the acceptance standards for respective defects, the parts shall be rejected.

(2) When two or more types of defects are present and the predominating defect is not significantly better than the acceptance standard, the part shall be considered borderline.

(3) Borderline castings shall be reviewed for acceptance or rejection by the cognizant procurement personnel.

(4) Gas holes or sand spots and inclusions allowed by this table shall be cause for rejection when closer than twice their maximum dimension to an edge or extremity of a casting.

ALUMINUM ALLOY CASTINGS, SAND COMPOSITE
4.7Cu - 0.75Ag - 0.35Mn - 0.30Mg - 0.22Ti (A201.0 - T7)
Solution Treated and Overaged
Structural Aircraft Quality

1. SCOPE

1.1. Form: This specification covers an aluminum alloy in the form of sand composite molded castings.

1.2 Application: Primarily for structural aircraft components.

1.3 Preproduction Qualification: The foundry supplying castings to this specification must have been pre-qualified by the purchaser in accordance with 4.4.

2. APPLICABLE DOCUMENTS: The following publications form a part of this specification to the extent specified herein. The latest of Aerospace Material Specifications (AMS) shall apply. The applicable issue of other documents shall be as specified in AMS 2350.

2.1 SAE Publications: Available from Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096.

2.1.1 Aerospace Material Specifications:

AMS 2350 - Standards and Test Methods
AMS 2360 - Room Temperature Tensile Properties of Castings
AMS 2804 - Identification Castings

2.2 ASTM Publications: Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASTM B557 - Tension Testing Wrought and Cast Aluminum and Magnesium Alloy
ASTM E18 - Test for Rockwell Hardness and Rockwell Superficial Hardness Metallic Materials
ASTM E34 - Chemical Analysis of Aluminum and Aluminum Alloys
ASTM E155 - Reference Radiographs for Inspection of Aluminum and Magnesium Castings, Series III
ASTM G44 - Alternate Immersion Stress Corrosion Testing in 3.5% Sodium Cloride Solution

2.3 Government Publications: Available from Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.

2.3.1 Federal Standards:

Federal Test Method Standard No. 151 - Metals; Test Methods

2.3.2 Military Specifications:

MIL-H-6088 - Heat Treatment of Aluminum Alloys
MIL-I-6866 - Inspection, Penetrant Method of
MIL-I-25135 - Inspection Materials, Penetrant

2.3.3 Military Standards:

MIL-STD-410 - Qualification of Inspection Personnel
MIL-STD-649 - Aluminum and Magnesium Products, Preparation for Shipment and Storage

MIL-STD-00453 - Military Standard Inspection, Radiographic
MIL-STD-1537 - Electrical Conductivity Test for Measurement of Heat Treatment of Aluminum Alloys, Eddy Current Method

3. TECHNICAL REQUIREMENTS

3.1 Composition: Shall conform to the following percentages by weight, determined by wet chemical methods in accordance with ASTM E34, by spectrographic methods in accordance with Federal Test Method Standard No. 151, Method 112, or by other approved analytical methods approved by purchaser:

	Foundry Melt Analysis		Tolerance For Casting Analysis	
	min.	max.	under min.	over max.
Copper	4.5	5.0	0.5	0.5
Silver	0.5	1.0	-	-
Manganese	0.20	0.50	-	-
Magnesium	0.25	0.35	0.05	0.05
Titanium	0.15	0.35		
Iron	-	0.05	-	
Silicon	-	0.05	-	
Other Impurities, each	-	0.05	-	
Other Impurities, total	-	0.15	-	
Aluminum	remainder		remainder	

3.2 Condition: Solution and precipitation heat treated (overaged).

3.3 Casting: Castings shall be produced from metal conforming to 3.1.

3.3.1 A melt shall be a single homogenous batch of molten metal to which all processing has been completed and the temperature has been adjusted ready for pouring castings.

3.3.2 A lot of castings shall be all castings poured from a single melt in not more than eight consecutive hours and solution and precipitation heat treated in the same heat treat batch.

3.4 Chemical Analysis Specimens: Shall be cast from each melt.

3.5 Integral Attached Coupons: Each casting will have a minimum of 2 integrally attached test coupons. The second coupon shall be left attached and only used in the event that reheat treatment is necessary.

3.6 Heat Treatment: Castings and integrally attached test coupons shall be solution and precipitation heat treated in accordance with MIL-H-6088 except as otherwise specified herein.

3.6.1 All castings and integrally attached test coupons shall be solution heat treated and overaged in such a manner as to ensure conformance to the requirements of 3.7. A step solution treatment of 945-965F for 2 hours minimum then stepped up to 970-990F for 14 hours minimum is recommended. An aging treatment at 365-375F (185-191C) for a minimum period of 5 hours is required.

3.6.2 The integrally attached test coupons shall remain attached to the casting until removed by an approved test facility of the purchaser which is independent of the foundry.

3.7 Properties: Castings and integrally attached test coupons shall conform to the following requirements:

3.7.1 Tensile Properties: Shall be as follows, determined in accordance with ASTM B557 and shall be used as basis for acceptance of castings.

3.7.1.1 Integrally Attached Test Coupons:

Tensile Strength, min. 62
Yield Strength at 0.2% Offset, min. 55
Elongation, min. 5%

3.7.1.2 Specimens Cut from Castings: Tensile properties of specimens cut from the casting shall be as follows:

3.7.1.2.1 Designated Casting Areas:

Tensile Strength, min. 60
Yield Strength at 0.2% Offset, min. 50
Elongation, min. 3%

3.7.1.2.2 Casting areas other than designated areas:

Tensile Strength, min. 56
Yield Strength at 0.2% Offset, min. 48
Elongation, min. 2%

3.7.1.2.3 When properties other than those of 3.7.1.2.1 or 3.7.1.2.2 are required, tensile test specimens taken from locations indicated on the drawing, from a casting chosen at random to represent the lot, shall have the properties indicated on the drawing for such specimens. Property requirements may be designated in accordance with AMS 2360.

3.7.2 Hardness of Castings: Castings, should have hardness of HRB minimum, 70 determined in accordance with ASTM E18, but castings shall not be rejected only on the basis of hardness.

3.7.3 Electrical Conductivity: Casting shall exhibit a minimum electrical conductivity of 31% IACS as determined by the procedure of MIL-STD-1537.

3.7.4 Stress-Corrosion Resistance: A specimen as in 4.3.5, cut from the designated area of the casting or an attached coupon shall show no evidence of stress corrosion cracking when tested for a period of 30 days in accordance with ASTM G44 at a stress of 75% of the specified minimum yield strength.

3.8 Quality

3.8.1 Castings as received by purchaser, shall be uniform in quality and condition, sound, and free from foreign materials and from internal and external imperfections detrimental to usage of the castings.

3.8.1.1 Castings shall have a surface finish in accordance with engineering drawing and NAS 823 and shall be well cleaned.

3.8.2 Castings shall be produced under foundry control. This control shall consist of pre-production examination of castings until proper foundry technique and controls are established which will produce castings that will meet the drawing quality and dimensional requirements.

3.8.3 Radiographic inspection shall be performed in accordance with MIL-STD-00453. In addition, Type 1 radiographic film shall be used, and a maximum unsharpness value of 0.003 inch (0.08 mm) and flaw sensitivity of 1% shall be maintained. ASTM E155 shall be used to define radiographic acceptance standards in accordance with Table 1.

3.8.4 Castings shall be subjected to fluorescent penetrant inspection in accordance with MIL-I-6866.

3.8.4.1 The fluoresent penetrant shall have a sensitivity level equivalent to group V of MIL-I-25135.

3.8.4.2 Personnel conducting the testing shall be qualified and certified in accordance with the requirements of MIL-STD-410.

3.8.4.3 Linear indications, cold shuts, cracks, and seams are cause for rejection.

3.8.4.4 Surface porosity is cause for rejection if the individual pores are closer than twice their maximum dimension to an edge or extremity of the casting or the pores form a linear indication; i.e., three or more are in a line and the distance between each indication is less than twice the maximum dimension of either adjacent indication.

3.8.4.5 Any individual indication which is three times longer than it is wide shall be considered a linear indication and shall be cause for rejection.

3.8.5 Castings shall not be repaired by peening, plugging, welding, or other methods, except as defined in 3.8.5.1.

3.8.5.1 Defects in the nondesignated areas of the casting may be removed and the castings repaired by welding in accordance with AMS 2694 and using A201 alloy filler metal. Final heat treatment and inspection shall be performed after the welding has been completed.

3.8.6 Castings shall not be impregnated, chemically treated, or coated to prevent leakage, unless specified or allowed by written permission of purchaser, designating the method to be used.

3.9 Marking

3.9.1 Each casting shall be identified by legible raised figures with part number, foundry identification, and serial number in the area indicated on the engineering drawing. The serial number shall be used only once to provide traceability to the processing of a particular part.

3.9.2 Each casting accepted by radiographic inspection shall be ink stamped in accordance with MIL-STD-00453.

3.9.3 Each casting accepted by penetrant inspection shall be ink stamped in accordance with MIL-I-6866.

3.9.4 Integrally attached test coupons or prolongations shall be identified by a vibroetched serial number corresponding with the casting serial number.

3.9.5 Castings and the accompanying reports shall identify the heat treat batch and melt number to the individual casting through the serial number.

3.9.6 When impregnation is specified or permitted by purchaser, castings shall be marked IMP by ink stamp.

4. QUALITY ASSURANCE PROVISIONS:

4.1 Responsibility for Inspection: The vendor of castings shall be respondible for obtaining all required tests at the purchaser's approved facilities. The removal and testing of tensile specimens from castings per 3.7.1.2 shall be performed at an approved facility independent of the foundry. Results of such tests shall be reported to the purchaser as required by 4.5. Purchaser reserves the right to perform such confirmatory testing as he deems necessary to ensure that the castings conform to the requirements of this specification.

4.2 Classification of Tests:

4.2.1 Acceptance Tests: Tests to determine conformance to requirements for composition (3.1), tensile properties of integrally attached test coupons (3.7.1.1), tensile properties of specimens cut from castings (3.7.1.2), electrical conductivity (3.7.3) and quality (3.8) are classified as acceptance tests and shall be performed on each casting, melt, or lot as applicable.

4.2.2 Periodic Tests: Tests to determine conformance to requirements for hardness (3.7.2) and stress-corrosion resistance (3.7.4) are classified as periodic tests and shall be performed at a frequency selected by the vendor unless frequency of testing is specified by purchaser. The frequency of testing specimens excised from castings is defined in 4.3.4.

4.2.3 Preproduction Tests: Tests to determine conformance to all technical requirements of this specification are classified as preproduction tests and shall be performed on the first-article shipment of castings to a purchaser, when a change in material or processing requires reapproval, as in 4.4, and when purchaser deems confirmatory testing is required.

4.2.3.1 For direct U.S. Military procurement, substantiating test data and, when requested, preproduction test material shall be submitted to the cognizant agency as directed by the procuring activity, the contracting officer, or the request for procurement.

4.3 Sampling: Shall be in accordance with the following:

4.3.1 One chemical analysis from each melt or one chemical analysis from each of two castings in each lot.

4.3.2 Each casting shall be radiographically and fluorescent penetrant inspected.

4.3.3 The electrical conductivity of an integrally attached test coupon of each casting shall be determined.

4.3.4 The destructive testing of castings for the evaluation of excised tensile specimen shall occur at the following frequency:

4.3.4.1 First 30 Castings Received: One casting of each 10 shall be selected for destructive testing.

4.3.4.2 Castings Received Thereafter: If no failure occurs in 4.3.4.1, one casting in each 25 consectively received there after shall be tested. If a failure occurs, the test frequency reverts to one in each 10 for the next 30 castings received.

4.3.4.3 Specimens shall conform to ASTM B557 and shall be either 0.500 in. (12.75 mm) diameter at the reduced gauge section or subsize specimens proportional to the standard round or standard sheet type specimens.

4.3.4.4 The tensile properties of an integrally attached test coupon from each casting shall be determined. Removal of the attached coupon shall only be performed by an approved test facility or the purchaser.

4.3.5 Specimens for stress-corrosion tests shall be round test specimens, not less than 0.250 in diameter in the reduced section. Whenever practicable, specimens shall be taken from the designated areas of the casting as shown on the engineering drawing. (Specimens from integrally attached test coupons are acceptable if size of the casting does not permit excision of 0.250 diameter specimen.)

4.4 Preproduction Approval:

4.4.1 Sample castings from new or reworked patterns shall be approved by purchaser before castings for production use are supplied.

4.4.1.1 Two preproduction castings shall be furnished to the purchaser. One casting shall have been dimensionally inspected by the vendor and the results shall be forwarded with the casting for approval. The second casting shall be for metallurgical evaluation by the purchaser. All the vendor results obtained to substantiate the metallurgical quality of the casting shall be included.

4.4.2 Vendor shall document the parameters for the control factors of processing which will produce acceptable castings; these shall constitute the

approved casting procedure and shall be used for producing production castings. If necessary to make any change in parameters for the control factors of processing, vendor shall submit for reapproval a statement of the proposed changes in processing and, when requested, sample test specimens, castings, or both. Production castings incorporating the revised operations shall not be shipped prior to receipt of written reapproval.

4.4.2.1 Control factors for producing castings include, but are not limited to the following:

Melting practice regarding control of:

Chemistry
Gas content
Grain size
Melt temperature

Molding procedure regarding:

Materials and assembly
Gating and risering systems

Heat treatment practice regarding:

Temperature and time parameters
Load density
Quenching procedure

Shop traveler describing the sequence of processing, inspection, and testing.

4.4.2.1.1 Any of the above control factors of processing for which parameters are considered proprietary by the vendor may be assigned a code designation. Each variation in such parameters shall be assigned a modified code designation.

4.5 Reports:

4.5.1 The vendor of castings shall furnish with each shipment three copies of a report showing the results of tests for chemical composition from each melt, tensile properties of attached specimens representing each casting; penetrant and radiographic inspection of each casting by serial number and specimens cut from casting if applicable. This report shall include the purchase order number, lot number, material specification number and its revision letter, part number, and quantity.

4.5.2 The vendor of finished or semi-finished parts shall furnish with each shipment three copies of a report showing the purchase order number, material specification number and its revision letter, contractor or other direct supplier of castings, part number, and quantity. When castings for making parts are purchased by the parts vendor, that vendor shall inspect each lot of castings to determine conformance to the requirements of this specification, and shall include in the report a

statement that the castings conform, or shall include copies of laboratory reports showing the results of tests to determine conformance. Castings produced by the parts vendor must be inspected in accordance with 4.1.

4.6 Resampling and Retesting:

4.6.1 Attached coupons

4.6.1.1 Retesting of the integrally attached coupon is permitted when an isolated flaw is evident on the fracture face of the broken tensile specimen.

4.6.1.2 Testing is required of an integrally attached test coupons after reheat treatment. The replacement specimen shall be taken from the second coupon which has remained integrally attached to the casting through the reheat treat process.

4.6.2 Tensile specimens excised from the casting.

4.6.2.1 Replacement of tensile specimens shall be allowed in accordance with ASTM B557 for poor machining, incorrect test procedure, malfunction of test equipment or fracture location.

4.6.2.2 Retesting of a tensile specimen excised from the castings is only permitted when the fracture face indicates an isolated gas hole, or piece of foreign material. Retesting shall be permitted by testing two adjacent specimens. Should it not be possible to obtain adjacent specimens, or if a replacement specimen also fails, then two additional castings shall be tested. The failure of a tensile specimen in a second casting shall be cause to consider the lot of castings suspect and the purchaser contacted for material review action. All castings shipped and in process since the last acceptable tensile test casting shall be reviewed for disposition.

4.6.2.3 All retest tensile specimens shall be located to represent as nearly as possible the quality of the metal of the original test. Isolated flaws that are discernable by production radiography may be avoided.

5. PREPARATION FOR DELIVERY

5.1 Identification: Castings shall be identified in accordance with AMS 2804.

5.2 Packaging:

5.2.1 Castings shall be prepared for shipment in accordance with commercial practice and in compliance with applicable rules and regulations pertaining to the handling, packaging, and transportation of the castings to ensure carrier acceptance and safe delivery. Packaging shall conform to carrier rules and regulations applicable to the mode of transportation.

5.2.2 For direct U.S. Military procurement, packaging shall be in accordance with MIL-STD-649, Level A or Level C, as specified in the request for procurement. Commercial packaging as in 5.2.1 will be acceptable if it meets the requirements of Level C.

6. ACKNOWLEDGMENT: A vendor shall mention this specification number and its revision letter in all quotations and when acknowledging purchase orders.

7. REJECTIONS: Castings not conforming to this specification or to authorized modifications will be subject to rejection.

8. NOTES:

8.1 Dimensions and properties in inch/pound units are primary; dimensions and properties in SI units are shown as the approximate equivalents of the inch/pound units and are not to be construed as standard for castings produced to SI dimensions.

8.2 Porosity on the surface of the stress corrosion specimen may accelerate corrosion due to entrapment of the saline solution and result in premature failure.

TABLE I.

Maximum acceptance defects in aluminum alloy castings (maximum permissible radiograph in accordance with ASTM E155)

Defects	Radiograph reference	Designated Areas	Other Areas
Gas holes	1.1	1	2
Gas porosity (round)	1.21	1	3
Gas porosity (elongated)	1.22	1	3
Shrinkage cavity	2.1	1	2
Shrinkage porosity or sponge	2.2	1	2
Foreign material (less dense)	3.11	1	2
Foreign material (more dense)	3.12	1	2
Segregation	...	none	none
Cracks	...	none	none
Cold shuts	...	none	none
Laps	...	none	none

NOTES:

(1) When two or more types of defects are present to an extent equal to or not significantly better than the acceptance standards for respective defects, the parts shall be rejected.

(2) When two or more types of defects are present and the predominating defect is not significantly better than the acceptance standard, the part shall be considered borderline.

(3) Borderline castings shall be reviewed for acceptance or rejection by the cognizant procurement personnel.

(4) Gas holes or sand spots and inclusions allowed by this table shall be cause for rejection when closer than twice their maximum dimension to an edge or extremity of a casting.

DETERMINATION AND ACCEPTANCE OF DENDRITE ARM SPACING IN ALUMINUM CASTINGS

1. SCOPE

1.1 This specification establishes a non-destructive test procedure to evaluate the dendrite arm spacing (DAS) of A356 and A357 aluminum castings.

2. APPLICABLE DOCUMENTS

This section is not applicable to this specification.

3. TECHNICAL REQUIREMENTS

3.1 Equipment

3.1.1	Portable Polishing Unit, Transpol, or equivalent	Max Erb Instrument Co.
3.1.2	Electropolishing Unit, Movipol, or equivalent	Max Erb Instrument Co.
3.1.3	Microstructure Replicating Unit, Transcopy, or equivalent	Max Erb Instrument Co.
3.1.4	Light Microscope with Camera Attachment	Commercial
3.1.5	Paper, Abrasive, 100 to 600 Grit	Commercial

3.2 TEST PROCEDURE

3.2.1 Microstructure Acceptance Criteria Determination

3.2.1.1 Testing of integrally attached coupons.

3.2.1.1.1 Two attached coupons shall be evaluated which represent a significant difference in dendrite arm spacing (DAS).

3.2.1.2 The DAS and ultimate tensile strength (UTS) of each coupon shall be determined.

3.2.1.3 The maximum DAS acceptable shall be determined in the following manner:

$$DAS_{max} = \left(\frac{DAS_2 - DAS_1}{UTS_1 - UTS_2}\right)(UTS_1 - UTS_3) + DAS_1$$

Where:

DAS_{max} = Maximum size DAS acceptable to meet minimum tensile properties (1×10^{-4} inches)

UTS_1 = Ultimate tensile strength of coupon with smallest DAS (Ksi)

UTS_2 = Ultimate tensile strength of coupon with largest DAS (Ksi)

UTS_3 = Ultimate tensile strength minimum required (Ksi)

DAS_1 = Size of DAS of coupon with smallest structure (1×10^{-4} inches)

DAS_2 = Size of DAS of coupon with largest structure (1×10^{-4} inches)

3.2.2 Casting Examination for Acceptance

3.2.2.1 The DAS shall be determined on the casting surface at each test location shown on the casting drawing. When test locations are not shown on the casting drawing, areas selected for the excision of tensile coupons shall be used.

3.2.2.2 The DAS in all test locations shall be equal or less than the maximum acceptable size determined in 3.2.1.

3.2.3 DAS Test Procedure

3.2.3.1 Prepolishing

3.2.3.1.1 Test locations shall be prepolished by equipment of 3.1.1 and 100 grit paper followed by 400 or 600 grit paper.

3.2.3.1.2 Prepolishing shall be sufficient to produce an outline of the secondary arm structure after etching.

3.2.1.3 Material removal during polishing shall not exceed 0.005 inch thickness.

3.2.3.2 Electropolishing and Electroetching

3.2.3.2.1 Prepolished test locations shall be electropolished and electroetched using Movipol electropolisher or equivalent approved by the Contractor.

3.2.3.2.2 The recommended polishing and etching solution when using Movipol is as follows:

Distilled Water	120 millilitres (ml)
Tartaric Acid	50 grams
Ethyl Alcohol	100 ml
Butyl Cellosolve	100 ml
Perchloric Acid (60 percent)	78 ml

3.2.3.2.3 When using Movipol, the recommended current density is 0.2 to 0.4 ampere; the etching time is 3 to 4 seconds.

3.2.3.3 <u>Microstructure Replication</u>

3.2.3.3.1 The microstructures of electroetched locations shall be transferred to a replica plate provided in the Transcopy kit, following the procedure described in the supplier's literature.

3.2.3.3.2 Any other method of microstructure replication, such as replicating tape, shall be approved by the Contractor.

3.2.3.3.3 The replica plates shall be individually identified by test location and placed within an envelope which identifies the test casting represented by the replicas.

3.2.3.3.4 Microstructure shall clearly distinguish the secondary arm spacing from the casting surface. Improper polishing, underetching, or overetching can produce a misleading microstructure.

3.2.3.3.5 If the microstructure is improperly polished, underetched, or overetched, the test location shall be repolished very lightly using 400 to 600 grit paper, re-electropolished and re-electroetched. The current density and etching time shall be established. Underetched locations shall not be re-electroetched without repolishing.

3.2.3.3.6 The test casting shall be rinsed in running water to remove the etching solution after the examination has been completed.

3.2.3.4 <u>Photographic Reproduction</u>

3.2.3.4.1 A photographic reproduction shall be made at a magnification of 100X in the area which most clearly defines the general microstructure.

3.2.3.4.2 Areas selected for evaluation shall be identified either directly on the photograph or on a copy of the photograph.

3.2.3.5 <u>Microstructure Evaluation</u>

3.2.3.5.1 Either of two methods of evaluation are acceptable; however, the measurement of clearly defined secondary dendrite arm spacing (DAS) is preferred. When this is not possible, the alternate procedure of measuring the distance between silicon particles located in a random manner along a single line shall be used. The measurement of DAS is possible if the microstructure of Figure 1 is obtained; however, if the microstructure of Figure 2 is obtained, then the alternate procedure is necessary.

3.2.3.5.2 All measurements used in the evaluation of a casting for acceptability shall be made by the same method.

3.2.3.5.3 <u>Preferred Measurement Method</u>: Extend a straight line across an area of well define structure such as illustrated in Figure 1. The line is drawn perpendicular to the growth direction of the secondary arms. The average distance between intercepts of silicon particles along the line shall be used to define the DAS of the structure. By measuring the total length of drawn line and counting the number of interceptions, the average DAS value can be determined in the following manner:

$$\text{DAS, inches: } \frac{\text{Length of Intercept Line (inches)}}{\text{Number of Interceptions}} \times \frac{1}{\text{Magnification}}$$

3.2.3.5.3.1 At least two areas of the microstructure shall be evaluated. The average value of the two areas shall be referred as the DAS of that test site.

3.2.3.5.4 Alternate Measurement Method - This alternate procedure consists of drawing a straight line of known length across the microstructure and counting the number of times the line is intercepted by silicon particles (see Figure 2). The average distance between silicon particles is then used to quantify the structure. Particle intercept distance (PID) is determined by the following:

$$\text{PID, inches} = \frac{\text{Length of Intercept Line (Inches)}}{\text{Number of Intercepts}} \times \frac{1}{\text{Magnification}}$$

3.2.3.5.5 At least two lines shall be drawn which vary in their orientation to each other as much as practical. The average PID of the two lines shall be reported.

3.2.3.5.6 In other sections of this specification, PID may be interchanged with DAS without changing the technical intent of this specification.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection: The testing facility shall be surveyed and approved by the casting purchaser. The test facility shall be responsible for the determination of an average measurement value from each test site.

4.2 Test Reports

4.2.1 The test results shall be itemized as average values from each test site on the casting or integrally attached test coupon.

4.2.2 A photograph or copy of the photograph of the microstructure at each test site shall be reported which clearly delineates the lines drawn for microstructure measurements.

4.2.3 The test laboratory shall maintain on file for a minimum period of 90 days the replica plate or tape used in the evaluation.

5. PREPARATION FOR DELIVERY: Not applicable.

6. Acknowledgement: A vendor shall mention this specification number and its revision letter in all quotations and when acknowledging purchase order.

7. REJECTIONS: Not applicable.

8. NOTES

8.1 Suppliers may obtain information pertaining to, or additional copies of, this specification by applying to the purchaser.

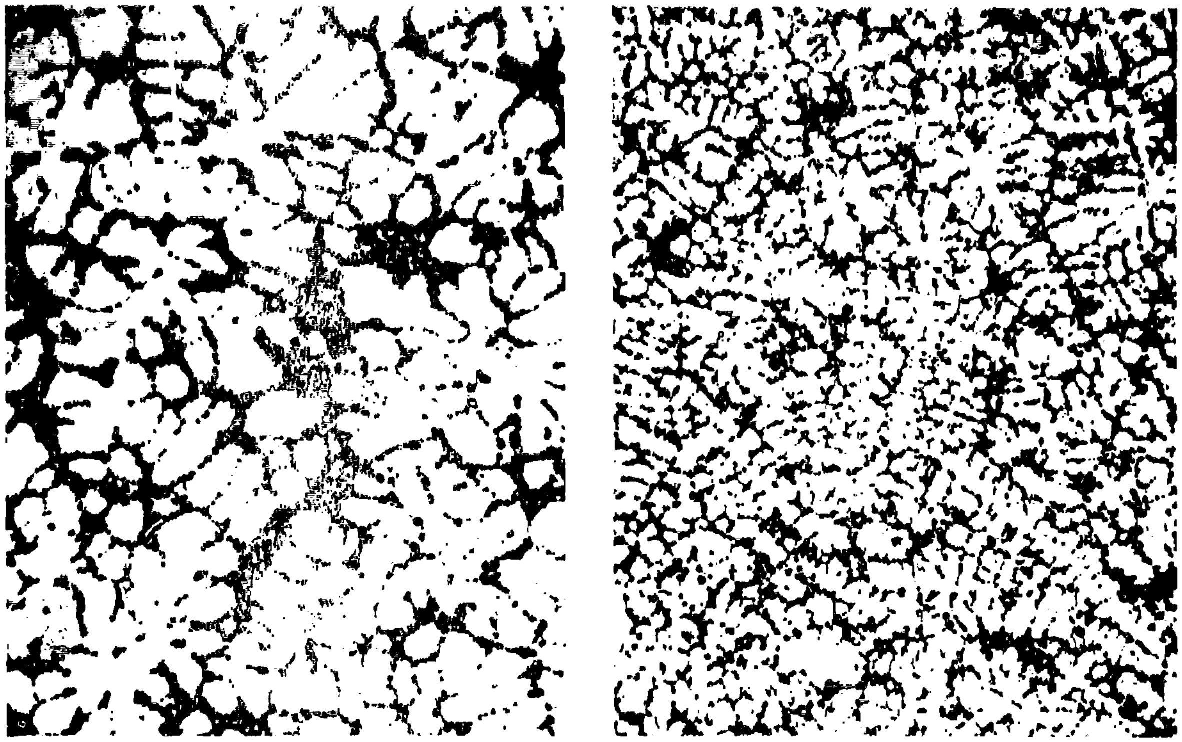

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FIGURE 1. MEASUREMENT OF DAS TAKEN IN SELECTED AREAS

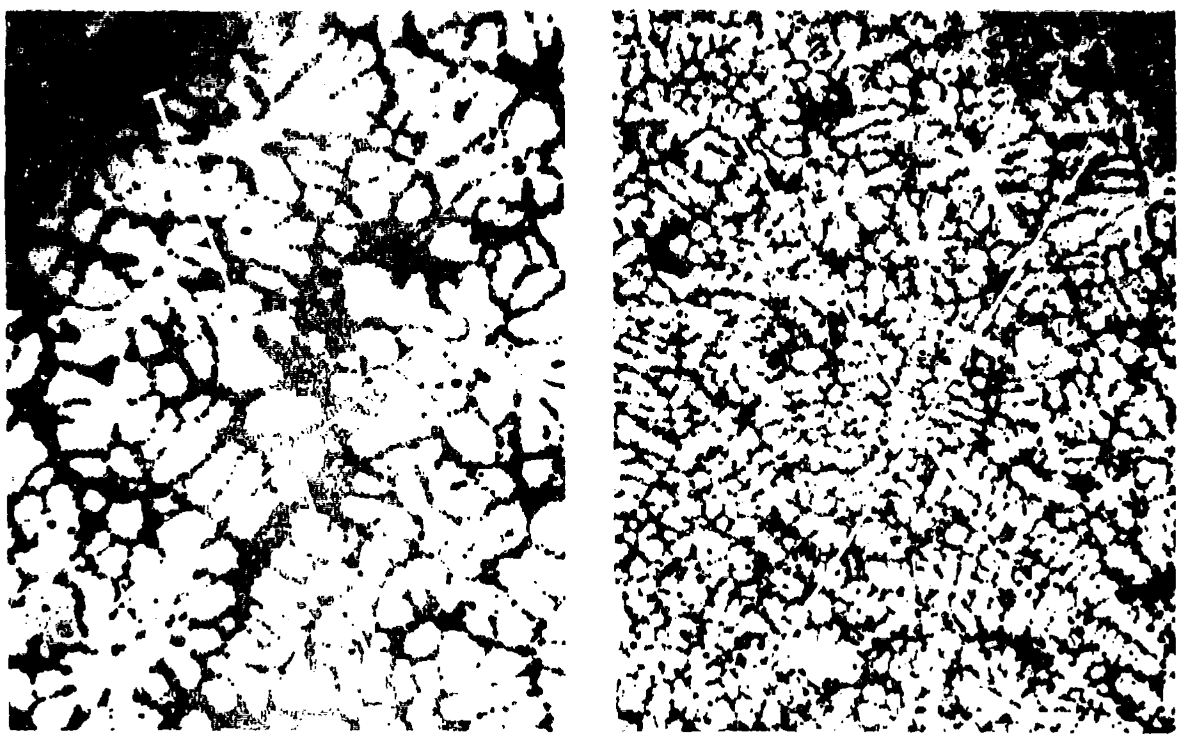

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FIGURE 2. MEASUREMENT OF PID ACROSS STRUCTURE

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